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Detection and Localization of Vibrotactile Signals in Moving Vehicles

by Andrea S. Krausman and Timothy L. White

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14. ABSTRACT

The focus of this research was to examine how well participants could detect and localize tactile signals while riding in moving vehicles. A ride motion simulator (RMS) was used to simulate a Bradley fighting vehicle or high mobility multipurpose wheeled vehicle traversing a cross-country course or gravel road. Two tactile display systems were used to provide signals. The wireless tactile control unit (WTCU) employed a vibrating motor similar to that of a cell phone or pager, and the Tactile Communications System (TACTICS) employed a plunger motor, which creates a tapping sensation. The signal strength of the TACTICS was driven at the optimal operating characteristics (TACTICS 1) or at operating characteristics similar to those of the WTCU system (TACTICS 2). For each system, eight tactors were positioned at 45-degree intervals (cardinal compass points) in two adjustable belts (plunger motor belt and pancake motor belt) worn around each participant's waist. Participants received tactile signals during a baseline (stationary) condition and while moving on the RMS. Results show that the TACTICS 1 performed consistently across all conditions, which may be because of the stronger, more distinct tactile signal generated by the TACTICS 1. Detection of tactile signals was affected by terrain, with fewer signals detected on the cross-country terrain. Additionally, the south tactor was detected less frequently than the other locations when participants were moving over the cross-country terrain.

15. SUBJECT TERMS

detection; localization; moving vehicles; tactile; tactile displays; signals; vibrotactile

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1. Background

Many challenges exist when one is designing interfaces with sensory feedback. Because many interfaces rely heavily on the visual channel for information processing, the use of visual cues or alerts may result in overload and fatigue (Hopp, Smith, Clegg, & Heggestad, 2005). Offloading information to other sensory modalities may help reduce overall workload (Wickens, 2002; Sarter, Waters, & Ho, 2003). For example, tactile displays that produce vibrations or a sense of pressure on the skin can be used as an alternate mode of conveying information that does not interfere with the more commonly used visual and auditory channels. Tactile displays can alert pilots of possible threats or other situations that may occur during a mission, especially when the visual channel is already overloaded or unavailable (Gilliland & Schlegel, 1994). For example, one tactile system called the Tactile Situation Awareness System was developed to enhance the spatial awareness of naval helicopter pilots (Rupert, Baker, McGrath, & Raj, 1996; Pai, 2003). Although tactile cues are effective "attention grabbers," they may be difficult to detect or may be "masked" when used in environments awash with vibration such as in moving vehicles (Furnell, Holmes, & King, 2003). Subsequently, using tactile signals for operations "on the move," such as those proposed by Future Combat Systems, may be problematic.

To date, the relevant literature has targeted issues such as the health effects of prolonged vibration exposure and how vehicle vibration interferes with the performance of visual and control tasks (Griffin, 1990). Few studies have addressed the use of tactile displays in moving vehicles (Van Erp, Van Veen, Jansen, & Dobbins, 2005). One article documents the development of a navigation system used by a blind boat driver in setting a world water speed record. Tactile signals were given to the blind boat driver; however, the vibrations from the tactile device could not be felt because of the vibrations generated by the boat traveling on the water's surface and the large engines (Castle & Dobbins, 2004). Changing the location of the tactors from the arm to the torso enhanced perception of the tactile cues. However, as tactile displays are integrated into other types of vehicles, especially vibrating combat vehicles, similar problems with perception of tactile cues may be experienced. Therefore, the primary objective of this research is to determine how vibration from ground vehicles affects detection and localization of tactile signals.

2. Objectives

The objectives explored within this study were to determine

(a) How the type of tactile system (plunger motor and pancake motor) affects the detection and localization of tactile signals while Soldiers are riding in a simulated moving vehicle.

(b) How different terrain affects the detection and localization of tactile signals while Soldiers are riding in a simulated moving vehicle.

(c) How tactor location affects detection and localization of tactile signals while Soldiers are riding in a simulated moving vehicle.

3. Method

3.1 Participants

Twelve participants, nine males and three females, were recruited from the pool of civilian personnel at Aberdeen Proving Ground, Maryland. Participants ranged in age from 24 to 54 years (mean *[M]* = 37.6, standard deviation *[SD]* = 11.6). Participation in this study was voluntary. Employees participated during their normal duty hours. Before participating, volunteers were screened for concerns about riding in a simulated vehicle (i.e., back problems, significant motion sickness problems). Participants were free to withdraw from the study at any time without penalty. A coding scheme was used to identify the data by participant number only (i.e., Subject 1) to maintain anonymity. All photographs taken during the course of the study were modified to ensure that participants could not be identified. The voluntary, fully informed consent of the persons used in this research was obtained as required by 32 Code of Federal Regulations 219 (Office of the Secretary of Defense, 1991) and Army Regulation 70-25 (Headquarters, Department of the Army, 1990).

3.2 Instruments and Apparatus

3.2.1 Ride Motion Simulator (RMS)

Participants were seated on a six-degree-of-freedom (6-DOF) RMS. The RMS uses a Moog 6-DOF 20000E motion platform (Moog, Inc., East Aurora, New York), capable of producing dynamics similar to those of military ground vehicles traversing secondary roads and cross-country terrain (figure 1). The platform is mounted on a hexapod design that is securely fixed to a non-movable surface and produces motion in the longitudinal (surge), lateral, vertical (heave), roll, pitch, and yaw directions. The platform supports a re-configurable cab that is large enough to allow the simulation of a crew station. The system is able to collect performance data regarding its motion. It was safety certified to permit use by civilians and experimenters in accordance with Regulation 385-17 (Aberdeen Test Center, 1993) before data collection began. In this study, participants were required to wear a seat belt around their laps for safety purposes. Controls were set to ensure that the ride motion did not exceed the safety standards. Specifically, the maximal acceleration of the RMS was limited to ±0.6 g lateral and longitudinal and –0.5 g to 0.7 g vertical. Emergency “stop” buttons were situated on the RMS cab, mounted on the rail to the right of the participant within arm’s reach, and at the control station for the experimenters to ensure that the RMS could be stopped immediately, if necessary.

Figure 1. Ride motion simulator.

For the purposes of this experiment, the RMS simulated a Bradley fighting vehicle (BFV) and a high mobility multipurpose wheeled vehicle (HMMWV) moving at 10 and 20 mph, respectively, over gravel terrain and a cross-country course. Ride dynamics were collected so that we could compare ride characteristics for each trial as needed and between past and future research experiments (appendix A).

3.2.2 Tactile Systems

3.2.2.1 Wireless Tactile Control Unit (WTCU)

The WTCU was developed by Dr. Lynette Jones at the Massachusetts Institute of Technology (MIT) under the Advanced Decision Architectures Collaborative Technology Alliance. WTCU system components include a vibrotactile display worn around the waist, a wireless control unit, and a battery (see table 1 for additional system specifications). For this experiment, the vibro-tactile display consisted of eight pancake motors or tactors (electromechanical transducers) that create a vibration similar to that of a pager or cell phone vibrating. Each tactor is encased in a plastic mold and measured 18.4 mm long, 17 mm wide, and 6 mm thick (figure 2). The plastic encasement makes the motor more robust and increases the contact area between the motor and the skin (Jones, Lockyer, & Piateski, 2006). A wireless control unit initiates the tactile signals. For the present study, each signal consisted of one tactor vibrating at 80 Hz for 500 ms. A 9-volt battery or rechargeable 7.2-volt lithium-ion battery can be used to power the WTCU. In the present study, a 9-volt battery was used.

Table 1. WTCU components and weights.

System Component	Weight (g)
Control Unit	156
Belt with eight tactors	153
Battery (9V)	46
Total	355

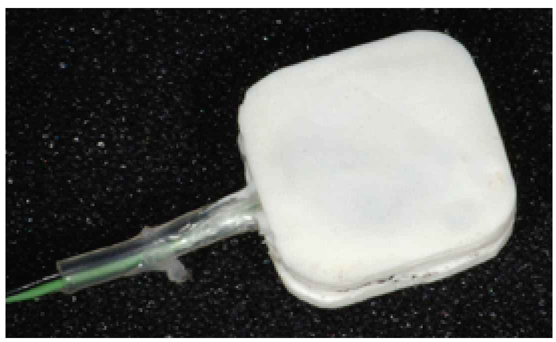

Figure 2. WTCU tactor.

3.2.2.2 Tactile Communication System (TACTICS)

TACTICS was developed by Dr. Richard Gilson at the University of Central Florida (UCF) under Defense Advanced Research Projects Agency contract number DAAE0703CL143 (Brill, Terrence, Stafford, & Gilson, 2006). Components of the TACTICS include a vibrotactile display worn around the waist, a wireless control unit, and a battery pack (see table 2 for additional system specifications). For this experiment, the tactile display consisted of eight linear actuators, called C2 tactors (Engineering Acoustics, Inc., Winter Park, Florida), approximately 1.2 inches in diameter, which create a “tap on the shoulder” sensation (figure 3). Tactile signals are initiated by the wireless control unit. Signal amplitude and frequency can be manipulated with TACTICS. For this experiment, a tactile signal consisted of a 250-Hz sinusoid, with two signal strengths that are referred to as TACTICS 1 and TACTICS 2. In the TACTICS 1 condition, the tactor signal strength was pre-set to a gain setting of 4—the operating characteristic chosen by UCF during the design of their system, which is approximately 24 dB above mean absolute threshold. In the second condition, identified as TACTICS 2, the signal strength was pre-set to a gain setting of 3, approximately 20 dB above mean absolute threshold, which equated to the signal strength of the WTCU system, as determined through a psychophysical loudness matching procedure (Stevens, 1959). Each signal consisted of one tactor vibrating for 500 ms. TACTICS is powered by a rechargeable 9.6-volt nickel metal hydride (Ni-MH) battery pack.

Table 2. TACTICS components and weights.

System Component	Weight (g)
Control Unit	312
Belt with eight tactors	255
Battery Pack	216
Total	783

Figure 3. C2 tactor (courtesy of www.eaiinfo.com).

3.2.3 Tactor Configuration

Eight tactors were positioned at 45-degree intervals (cardinal compass points) and arranged in two adjustable belts (figure 4). This spatial con-figuration was used to facilitate vibrotactile localization within the limitations of human perception (Cholewiak, Brill, & Schwab, 2004). One belt contained the C2 tactors, and the other contained the MIT tactors.

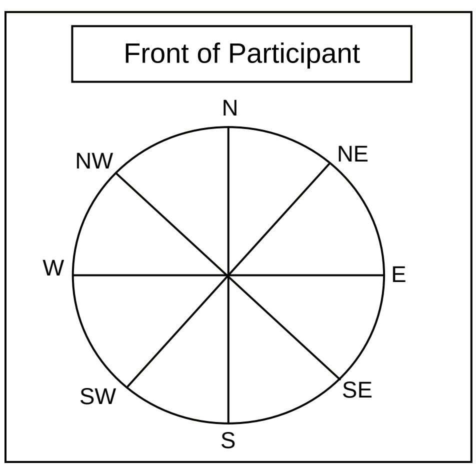

Figure 4. Tactor configuration.

3.2.4 Questionnaires

A health and demographics questionnaire was used to collect data pertaining to demographics, medical conditions, and susceptibility to motion sickness from the participants (appendix B).

3.2.5 Other Equipment

A Dell[1] Latitude D800 laptop was used to generate and send the tactile signals to the receiver boxes of the two tactile systems. Communication between the laptop and the tactile systems was accomplished via a Bluetooth[2] wireless dongle.

3.3 Experimental Design

3.3.1 Independent Variables

A 2 x 2 x 3 x 8 within-subjects design was used with four independent variables: vehicle type, terrain, tactile system, and tactor location. The independent variables and associated levels are shown in table 3. Presentation order for vehicle type, terrain, and tactile system were counter-balanced with the use of a Latin square (table 4). Tactile signals were presented randomly at the eight tactor locations.

Table 3. Independent variables and levels.

Variable	Levels
Vehicle type	BFV, HMMWV
Terrain	cross country, gravel
Tactile system	MIT, TACTICS 1, TACTICS 2
Tactor location	north, northeast, east, southeast, south, southwest, west, northwest

Table 4. Presentation order.

Participant	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12
1	A	B	L	C	K	D	J	E	I	F	H	G
2	B	C	A	D	L	E	K	F	J	G	I	H
3	C	D	B	E	A	F	L	G	K	H	J	I
4	D	E	C	F	B	G	A	H	L	I	K	J
5	E	F	D	G	C	H	B	I	A	J	L	K
6	F	G	E	H	D	I	C	J	B	K	A	L
7	G	H	F	I	E	J	D	K	C	L	B	A
8	H	I	G	J	F	K	E	L	D	A	C	B
9	I	J	H	K	G	L	F	A	E	B	D	C
10	J	K	I	L	H	A	G	B	F	C	E	D
11	K	L	J	A	I	B	H	C	G	D	F	E
12	L	A	K	B	J	C	I	D	H	E	G	F

A = wheeled, gravel, TACTICS 1	E = tracked, cross country, TACTICS 1	I = wheeled, gravel, MIT
B = wheeled, cross country, TACTICS 2	F = wheeled, cross country, TACTICS 1	J = tracked, cross country, TACTICS 2
C = tracked, gravel, MIT	G = tracked, gravel, TACTICS 1	K = wheeled, cross country, MIT
D = wheeled, gravel, TACTICS 2	H = tracked, gravel, TACTICS 2	L = tracked, cross country, MIT

[1]Dell is a trademark of the Dell Corporation.

[2]The Bluetooth word mark and logo are registered trademarks owned by the Bluetooth SIG, Inc.

3.3.2 Dependent Variables

Two dependent variables were measured: (a) percentage of signals detected, and (b) overall percentage of signals correctly localized. The percentage of signals detected measured whether a signal was perceived, regardless of its location. For the overall percentage of signals correctly localized, both missed signals (failure to detect) and incorrect localizations were counted as errors, thereby measuring overall system performance.

3.4 Procedures

First, each participant received a volunteer agreement affidavit (appendix C) to read, initial, and sign. Participants who elected not to sign the volunteer affidavit were free to return to their normal duties without penalty. Next, participants answered the health and demographics questionnaire. Following completion of the questionnaire, participants completed the orientation session, which helped familiarize them with the purpose of the experiment, the equipment setup, and the safety procedures prescribed for the experiment. Any questions were answered fully. Following the orientation, participants completed a training session. For this, they donned an undershirt (in a private room) that had six belt loops sewn around the shirt at waist level (just below the navel) to ensure that the tactile belts stayed in place. An experimenter placed the tactile belt on the participant, using all the belt loops. Because of the dynamic movements of the RMS, the wireless control units for both the WTCU and TACTICS were firmly attached to a load-bearing vest worn over the undershirt. Participants were trained first on the MIT system, then on TACTICS 1 and TACTICS 2. For each training session, 16 tactile signals were presented and participants verbally indicated the location of the vibration they received, using the cardinal compass points (figure 4). Verbal feedback was provided if participants responded incorrectly. Upon completion of the training, the participant was seated on the RMS and completed a practice trial to become familiar with how the simulator operates. During the practice trials, participants also received 16 tactile signals with each system, two signals at each compass point. Again, participants verbalized the location of each signal. Verbal feedback was given for incorrect responses. Following completion of the practice trial, any questions were answered and participants began the experiment.

For the experiment, participants donned a tactile system and were randomly assigned to a treatment condition. They were seated on the stationary RMS, and a baseline measure for each tactile system was taken. For the baseline, participants sat on the stationary RMS and received 16 tactile signals (two at each cardinal compass point), verbally indicating the location of the vibration they received using the cardinal compass points. No experimenter feedback was given during the baseline or the experimental trials. After the baseline measures were complete, participants began the ride portion of the experiment. During the simulated ride, the tactile system generated tactile signals that were delivered to the participant's waist at each of the 45-degree positions. Participants verbally indicated the location of the vibration they received using the cardinal compass points. Each treatment condition lasted for approximately 3 minutes, and participants received 16 tactile signals, two signals at each of the compass points. Tactile signals were presented at random intervals to prevent participants from anticipating when they would receive a signal. Upon completion of the experiment, an informal interview was conducted with each participant to obtain his or her opinion about the tactile systems and their performance. Approximately 1.5 hours were necessary for each participant to complete the experiment.

3.5 Data Analysis

Since the BFV and HMMWV traveled at different speeds (10 mph and 20 mph, respectively), separate analyses of variance (ANOVAs) were performed for each vehicle with terrain, tactile system, and tactor location as the independent variables. Statistical significance was concluded when $p < 0.05$. Significant effects were examined *post hoc* with Tukey's Honestly Significant Difference (HSD) test.

4. Results

4.1 Baseline (stationary)

4.1.1 Percent Detected

Participants were able to detect 100% of the tactile signals during the baseline condition.

4.1.2 Overall Percent Correct

Analysis of the baseline data indicates that system had an effect on the percentage of tactile signals correctly localized, $F(2, 22) = 7.45$, $p = .00346$. *Post hoc* tests showed that a significantly lower percentage of signals was correctly localized with the MIT system than with the TACTICS 1 and TACTICS 2 (figure 5). No significant differences were indicated between TACTICS 1 and TACTICS 2. No other main effects or factor interactions were found. Descriptive statistics (means and standard deviations) are presented in appendix D.

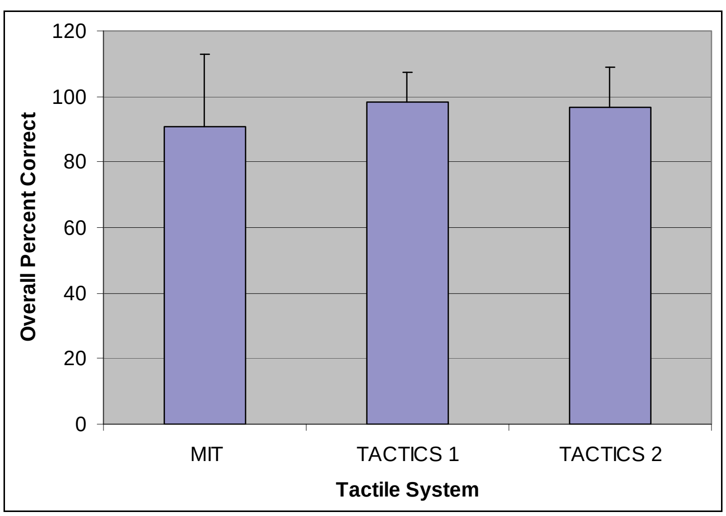

Figure 5. Mean (SD) percent correct by system (baseline).

4.2 Bradley Trials

4.2.1 Percent Detected

The ANOVA conducted on the BFV percentage of detected signals revealed significant interaction effects of system and terrain, $F(2, 22)$, = 6.66, p = .0055, and main effects of system, $F(2, 22)$ = 4.91, p = .0173, and terrain $F(1, 11)$ = 16.95, p = .0017. There were also significant interaction effects of terrain and tactor location, $F(7, 77)$ = 3.06, p = .0067, and a main effect of tactor location, F(7, 77) = 3.26, p = .0044. No other main effects or factor interactions were found. Descriptive statistics (means and standard deviations) for all significant effects are given in appendix D.

The nature of the System x Terrain interaction is depicted in figure 6. Subsequent analysis showed that when participants were moving over the shifting cross-country terrain, detection rates for the TACTICS 1 and TACTICS 2 were significantly higher than for the MIT system; however, no significant differences were found between TACTICS 1 and TACTICS 2 (figure 6). In contrast, for the gravel terrain, detection rates were relatively consistent across the three tactile systems. From these data and closer examination of figure 9, we can assume that the system main effect is primarily attributable to the interaction of system and terrain. With respect to the significant Terrain x Location interaction (figure 7), *post hoc* analysis showed that for the cross-country terrain, detection rates were significantly lower at the south tactor location than at the other tactor locations except southwest, while detection rates for the gravel terrain remained relatively consistent across the eight tactor locations, which suggests that the location main effect is affected by the Terrain x Location interaction. Similarly, the terrain main effect can be attributed to the System x Terrain (figure 6) and Terrain x Location interactions (figure 7).

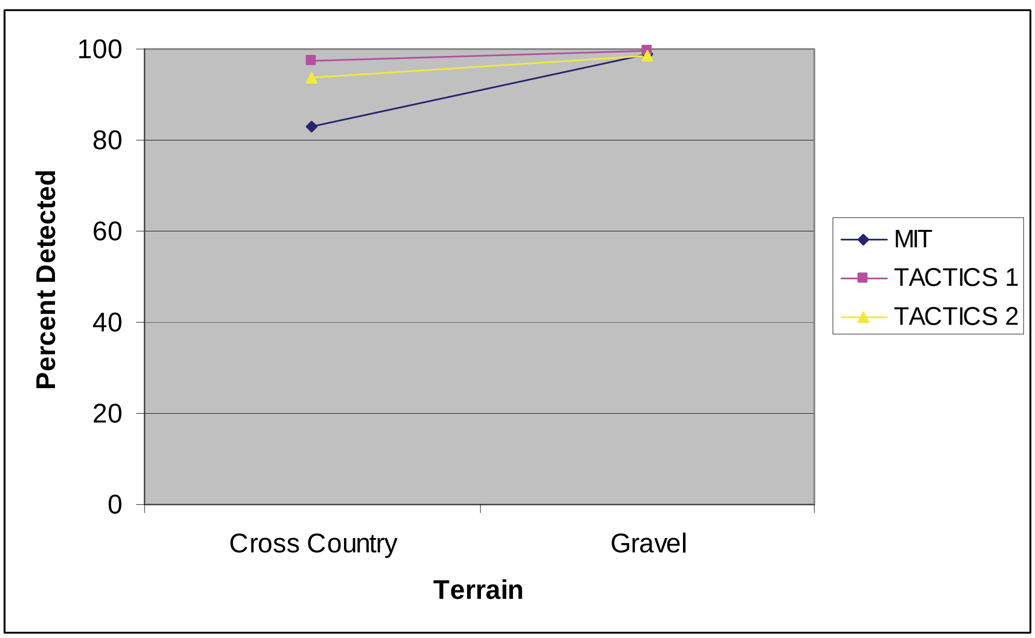

Figure 6. System x Terrain interaction (BFV - percent detected).

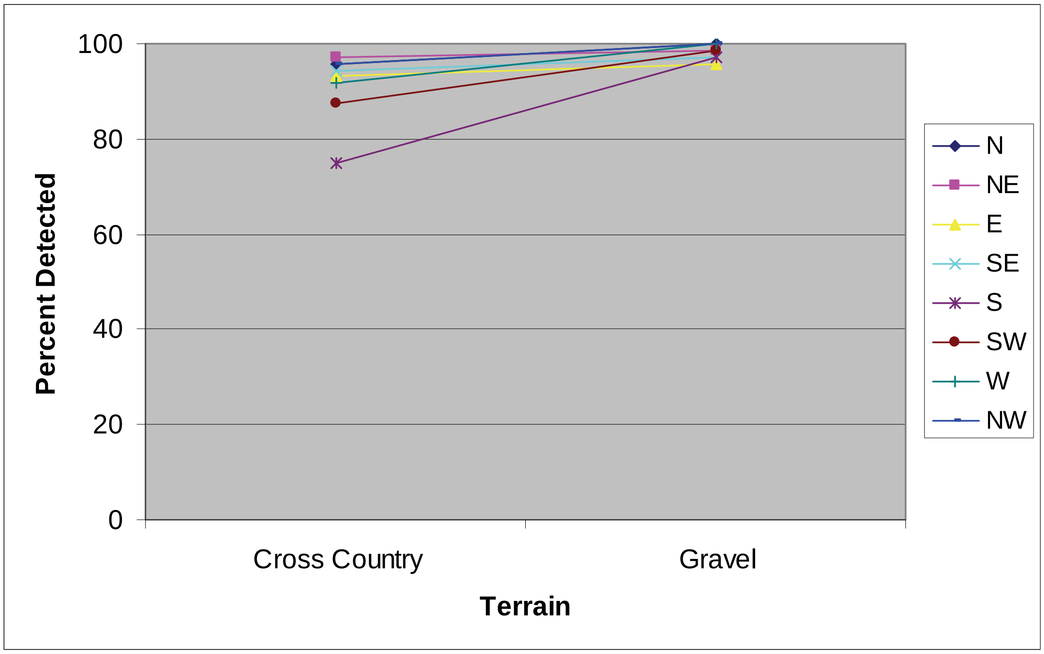

Figure 7. Terrain x Location interaction (BFV - percent detected).

4.2.2 Overall Percent Correct

The analysis of the overall percent correct data for the BFV showed a significant System x Terrain interaction, $F(7, 77) = 6.41$, $p = .0064$, with main effects of both system, $F(2, 22) = 8.08$, $p = .0023$, and terrain, $F(1, 11) = 52.48$, $p < .0001$. A significant interaction effect of system and location, $F(14, 154) = 2.00$, $p = .0213$ was also indicated by the analysis. No other main effects or factor interactions were found. Descriptive statistics (means and standard deviations) for all significant effects are presented in appendix D.

Regarding the System x Terrain interaction shown in figure 8, the cross-country terrain resulted in higher localization rates with TACTICS 1 and TACTICS 2 than for the MIT system. However, localization rates with TACTICS 1 and TACTICS 2 were not different from each other. For the gravel terrain, results are similar to the BFV detection data with consistent localization rates across the three tactile systems. From these data, it appears that the main effects of system and terrain are explained by the System x Terrain interaction (figure 8). As shown in figure 9, there was a significant interaction effect of system and location. Tukey's HSD test indicated that for the MIT system, localization rates were significantly higher at the northeast location than at the south location, with no significant differences in localization rates at the various tactor locations for TACTICS 1 and TACTICS 2.

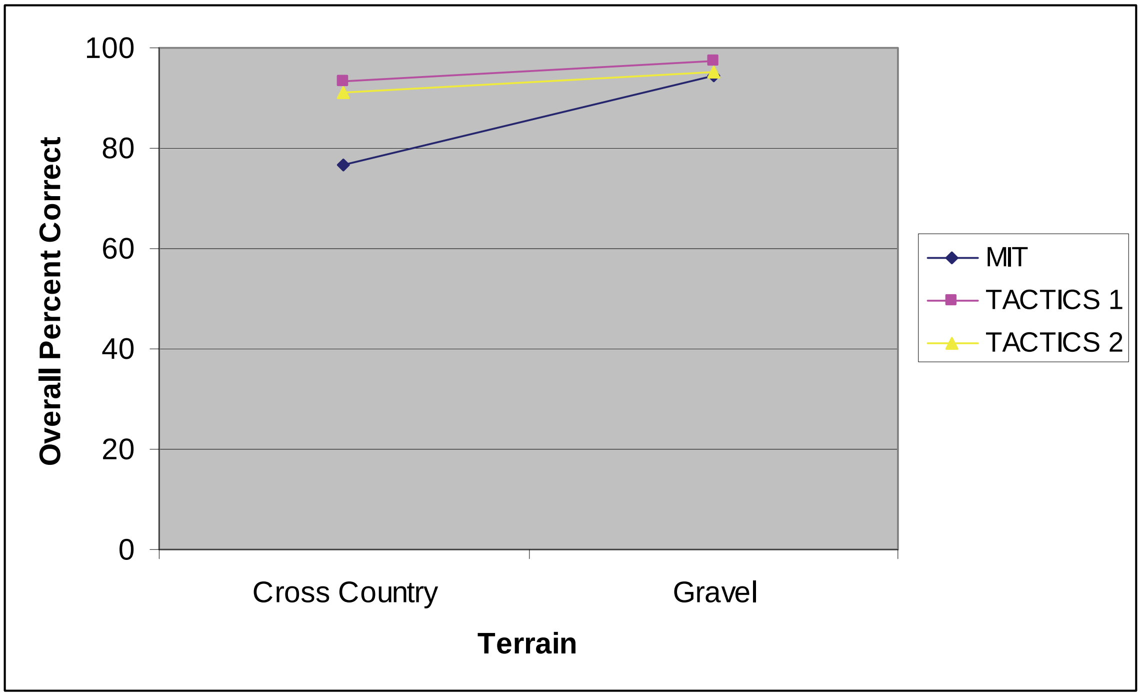

Figure 8. System x Terrain interaction (BFV - overall percent correct).

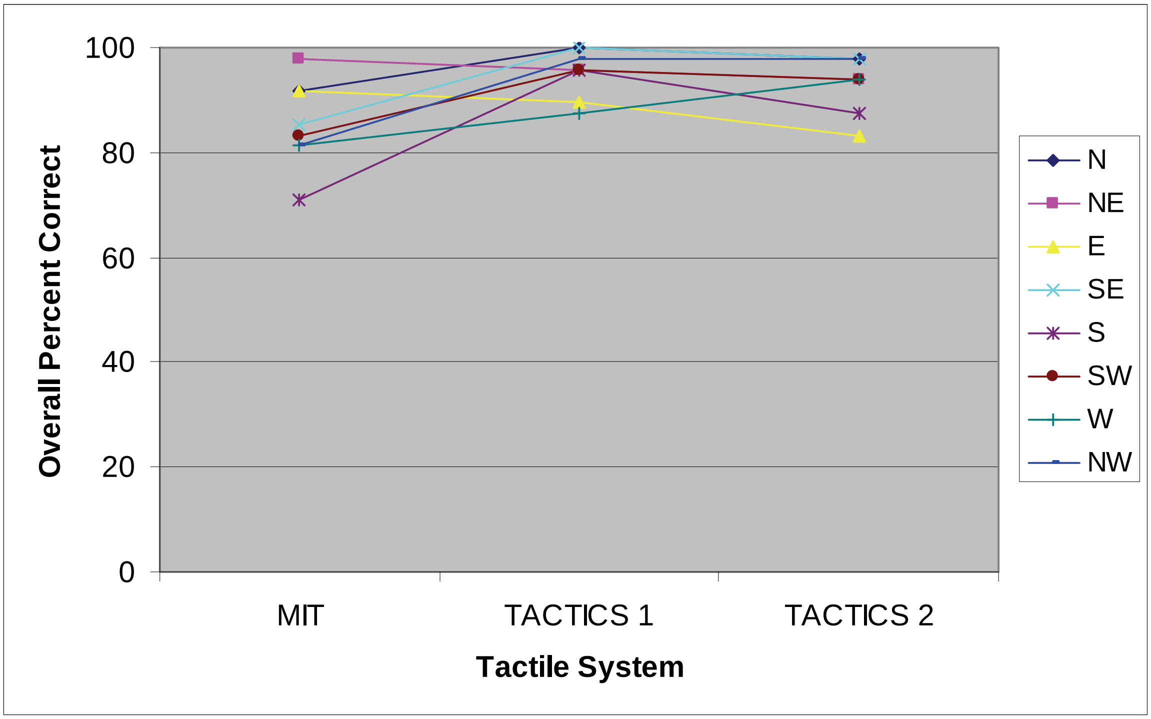

Figure 9. System x Location interaction (BFV - overall percent correct).

4.3 HMMWV Trials

4.3.1 Percent Detected

With respect to the percentage of detected signals for the HMMWV, several significant interaction effects were identified, namely, an interaction between system and terrain, $F(2, 22)$, = 8.64, p = .0017; terrain and location, $F(7, 77) = 2.44$, $p = .0257$; and system and location, $F(14, 154) = 2.16$, $p = .0116$. Results also showed significant main effects of terrain, $F(1, 11) = 15.09$, $p = .0025$; system, $F(2, 22) = 6.88$, $p = .0048$; and tactor location, F(7, 77) = 5.52, $p < .0001$. No other significant effects or factor interaction were found. Descriptive statistics for all significant effects are given in appendix D.

The System x Terrain interaction is illustrated in figure 10. *Post hoc* analyses showed that when participants were moving over the cross-country terrain, detection rates for the TACTICS 1 were significantly higher than for the MIT and TACTICS 2, with no significant differences in detection rates between MIT and TACTICS 2. For the gravel terrain, detection rates were relatively consistent across the three tactile systems (figure 10). Regarding the Terrain x Location interaction (figure 11), *post hoc* analyses showed that for the cross-country terrain, detection rates were significantly lower at the south tactor location than at the other tactor locations except southeast and southwest. Detection rates were also significantly higher at the northeast location compared to southeast and southwest. Additionally, detection rates were significantly higher at the east location compared to southeast. Detection rates for the gravel terrain remained relatively consistent across the eight tactor locations (figure 11). From these data and closer examination of figures 10 and 11, we can assume that the terrain main effect can be attributed to the interaction effects of system and terrain and terrain and location.

The System x Location interaction (figure 12) was also significant, with detection rates for the MIT significantly lower at the south tactor location than at the other locations except southeast and southwest. Similarly, detection rates with TACTICS 2 were significantly lower at the south location than at all other locations except southwest. With regard to TACTICS 1, detection rates were consistent across tactor locations. As mentioned previously, the analysis showed significant main effects of system and location. Based on results of the analysis, it appears that the effect of system can be accounted for by the System x Terrain interaction and the System x Location interaction. Moreover, it appears that the System x Location interaction may also help explain the location main effect.

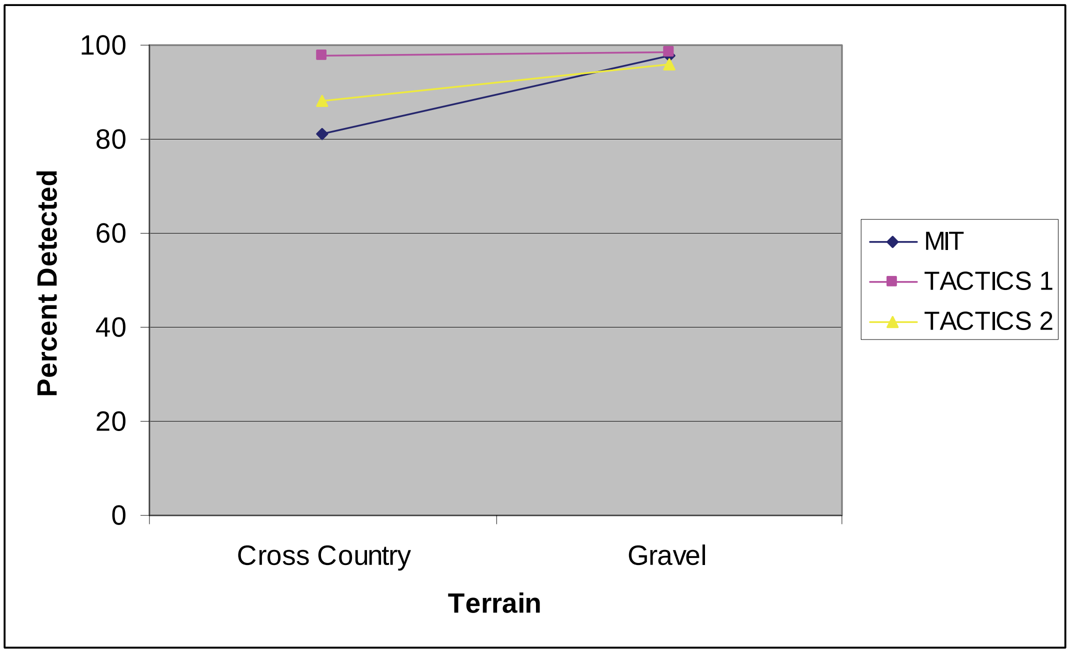

Figure 10. System x Terrain interaction (HMMWV - percent detected).

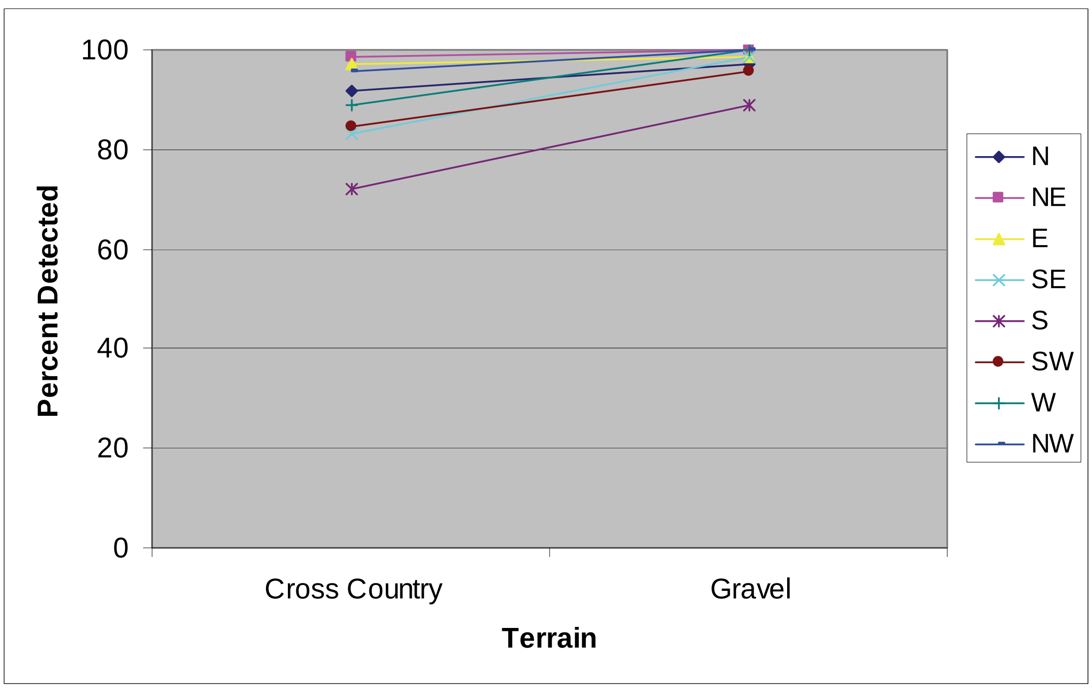

Figure 11. Terrain x Location interaction (HMMWV - percent detected).

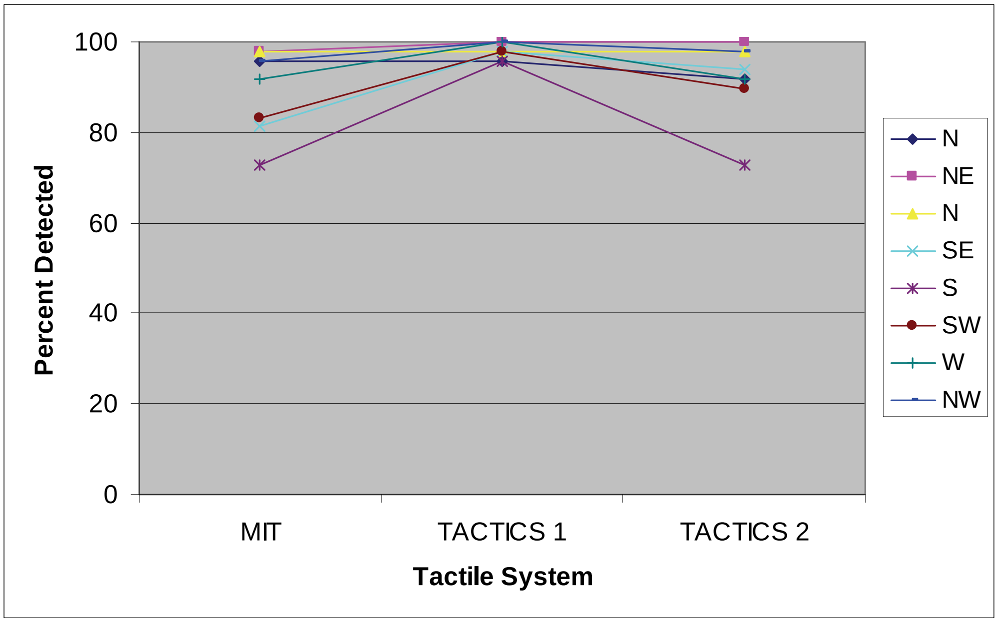

Figure 12. System x Location interaction (HMMWV - percent detected).

4.3.2 Overall Percent Correct

Analysis of the overall percent correct data for the HMMWV showed a significant System x Terrain interaction, $F(2, 22) = 7.18$, $p = .0040$. Three main effects were also shown: terrain, $F(1, 11) = 52.48$, $p < .0001$; system, $F(2, 22) = 8.08$, $p = .0023$; and location, $F(7, 77) = 3.68$, $p = .0018$. No other main effects or interactions were found. Descriptive statistics for all significant effects are given in appendix D.

Post hoc analysis of the System x Terrain interaction (figure 13) showed that localization rates were significantly higher with TACTICS 1 than the MIT system, with no significant differences in localization rate between TACTICS 1 and TACTICS 2 or MIT and TACTICS 2. On the gravel terrain, localization rates were consistent across the three tactile systems. Subsequently, the main effects of system and terrain can be interpreted in light of the System x Terrain interaction. However, it appears that the effect of tactor location is independent of system and terrain and can be interpreted on its own. According to results of Tukey's HSD analysis of the location data, localization rates were significantly lower at the south location than at the north, northeast, and northwest locations. Additionally, the northeast position elicited significantly higher localization rates than west (figure 14).

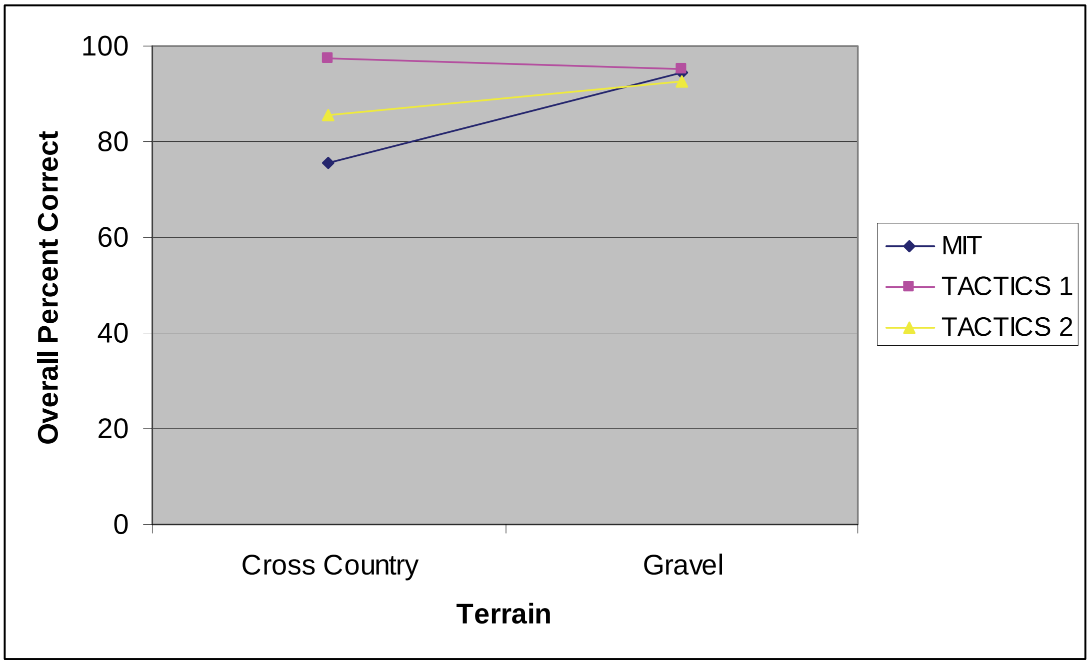

Figure 13. System x Terrain interaction (HMMWV - overall percent correct).

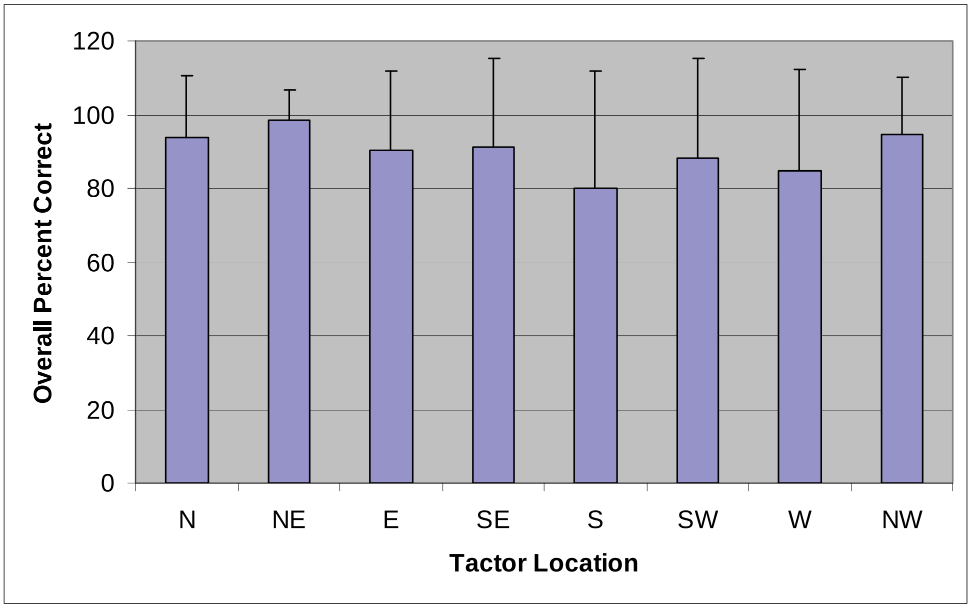

Figure 14. Mean (SD) overall percent correct by tactor location (HMMWV - overall percent correct).

5. Discussion

Determining how vehicle vibration affects detection and identification of tactile signals is important in the design of tactile displays. The objectives of this research were to identify how riding in a simulated HMMWV and BFV over different terrain impacts the detection and localization of tactile signals and to use these results to develop recommendations for designing tactile displays that are compatible in environments awash with vibration. Findings from the present study will be discussed in light of the study objectives and previous research.

The first objective of this study was to determine how tactile system type affects the detection and localization of tactile signals. Since tactile systems may be implemented in vehicles as an alerting mechanism or for navigation, it is important that users can reliably perceive the signals, even in the presence of the vehicle's vibration. According to the moving trial analyses, both detection and localization were affected by tactile system. Of particular interest is the significant System x Terrain interaction that occurred for the BFV and HMMWV (figures 6, 8, and 10). Overall, for both vehicles, we can conclude that there are significant differences in detection and localization between the MIT system and at least one of the TACTICS on the cross-country terrain but no significant differences between systems on gravel terrain. Specifically, detection rates with the MIT system were degraded by as much as 20%, and localization performance was reduced by as much as 29% on the cross-country terrain. From these results, it appears that the stronger, more distinct TACTICS signal afforded better detection and localization than the MIT system. One potential explanation for this result is the difference in the type of motors or actuators that comprise the tactile displays. For example, the MIT system uses a pancake motor that spins inside a casing, whereas the TACTICS use a plunger motor that "taps" against the skin, creating a distinct concentrated signal. Further, since the MIT pager motors operate at a relatively low frequency (approximately 80 Hz) and the C2 tactors operate at a higher frequency (250 Hz), some degree of frequency masking may have been responsible for the differences in performance between the tactile systems. Vehicle vibration is generally low frequency vibration, which means the low frequency vibration of the MIT pager motor is subject to masking to a much greater degree than frequencies beyond the vehicular motion bandwidth, namely, that of the C2 tactor.

During the post-experiment interview, several participants indicated that the TACTICS provided a stronger signal that was easier to feel and localize compared to the MIT signal. An interesting finding of the analysis is with regard to the differences across systems for the baseline trials. It was anticipated that since the RMS was not moving, detection and localization would be consistent across the three systems. While there were no differences in detection, the analysis showed significant differences in localization rates between the tactile systems. Providing an explanation for this result is difficult, especially in light of the fact that detection and localization were not affected by system when participants were moving over the gravel terrain.

With respect to the second objective, we can conclude that terrain had significant effects on detection and localization of tactile signals, which is apparent when we examine the Terrain x Location interaction, as well as the System x Terrain interaction described previously. As shown in figures 7 and 11, detection rates differed across the tactor locations on the cross-country terrain yet remained consistent over the gravel terrain. More specifically, on the cross-country terrain, the south tactor location was detected less frequently than other tactor locations, possibly resulting from the south tactor, which was situated at the small of the back, being pressed against the back of the seat as the participant rode over the simulated terrains. From these data and the vehicle ride profiles shown in appendix A, it appears that the bumpy, shifting terrain of the cross-country course made detection of tactile signals more difficult than the rather benign and predictable gravel terrain. Since we specifically included a wheeled and tracked vehicle in this study, it would be interesting to examine differences between the vehicles to determine if the vehicle type would affect participants' ability to feel and identify tactile signals. However, since the BFV and HMMWV traveled at two different speeds (10 and 20 mph, respectively), these comparisons cannot be made but should be included in future endeavors.

The final objective was to determine if there are certain locations around the belt that are more difficult to localize than others. Data from the System x Location interaction for the BFV and HMMWV indicate that the south tactor location was detected less frequently when participants were moving over the cross-country course. However, these results are inconsistent with those in the literature. For example, Cholewiak et al. (2004) examined localization of tactile stimuli around the abdomen and found almost perfect localization for the navel, spine, and adjacent positions, while localization at the sides was poorer. Moreover, Van Erp (2005) found that pointing errors were smallest for tactile stimuli presented at the navel, with more errors for stimuli presented at the sides. From these studies, it seems reasonable to conclude that the spine and navel may act as anatomical landmarks, resulting in superior localization compared to the sides of the abdomen, as was discussed by Cholewiak et al. (2004). It is unclear why the results from the present study are inconsistent with others in the literature. One possible explanation is that the objective of studies cited was to identify body locations that respond best to tactile stimuli and to investigate the optimum number of tactors. Therefore, studies were typically conducted in a laboratory devoid of environmental influences such as vibration. In the present study, the bumpy, shifting vehicle movements over the cross-country course and the interaction with the seat back may have interfered with detection and localization at the south location since it is situated at the indentation of the spine. Additional work should be done to determine if increasing the intensity at the south location when participants are moving over rough terrain would improve detection and localization.

An important finding that deserves mentioning is that the TACTICS 1 performed consistently across all experimental conditions. As described in the apparatus section, TACTICS 1 elicited a stronger signal than the MIT and TACTICS 2, which may explain the consistent performance. Although performance was consistent with TACTICS 1, there are some additional issues that deserve consideration. For example, during the post-experiment interviews, participants mentioned that the noise generated by the C2 tactor used in the TACTICS was very noticeable. Although this may not be an issue for Soldiers remaining inside a vehicle (such as a driver or a vehicle commander), it could be problematic for Soldiers who dismount. Another concern for a Soldier who dismounts is the weight of the TACTICS (approximately 783 grams or 1.7 lb) plus additional batteries, which is in addition to the load a Soldier is already required to carry. As can be seen from the data in tables 1 and 2, TACTICS is more than twice the weight of the MIT system. Additional work should investigate ways to reduce the overall system weight but still provide adequate signal intensities.

6. Conclusions and Future Work

Results of the present study demonstrate that tactile signals may be feasible for relaying information to Soldiers inside vehicles. If implemented, tactile technology could enhance the information management of Soldiers, thereby improving their situational awareness and survivability on the battlefield. However, several challenges still remain that should be investigated in order to ensure the effective design of tactile displays, namely, how manipulating tactile signal characteristics, such as frequency and amplitude, can enhance detection and localization of tactile signals in moving vehicles, especially over rough, unpredictable terrain. Another beneficial topic to be explored is to see how adding a cognitive secondary task impacts the detection of tactile signals.

7. References

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REVISIONS				
ZONE	REV	DESCRIPTION	DATE	APPROVED
	-	E RELEASE	19990312	LRO/DJF
	A	INSERTED NEW SHEET 4, REORDERED SHEET NUMBERS	20000411	LRO/TP
	B	REVISED PICTORIAL ELE CONT	20000807	LRO/TP
	C	PICTORIAL CHANGE SH 5 & 7	20010208	LRO/TP

NOTES

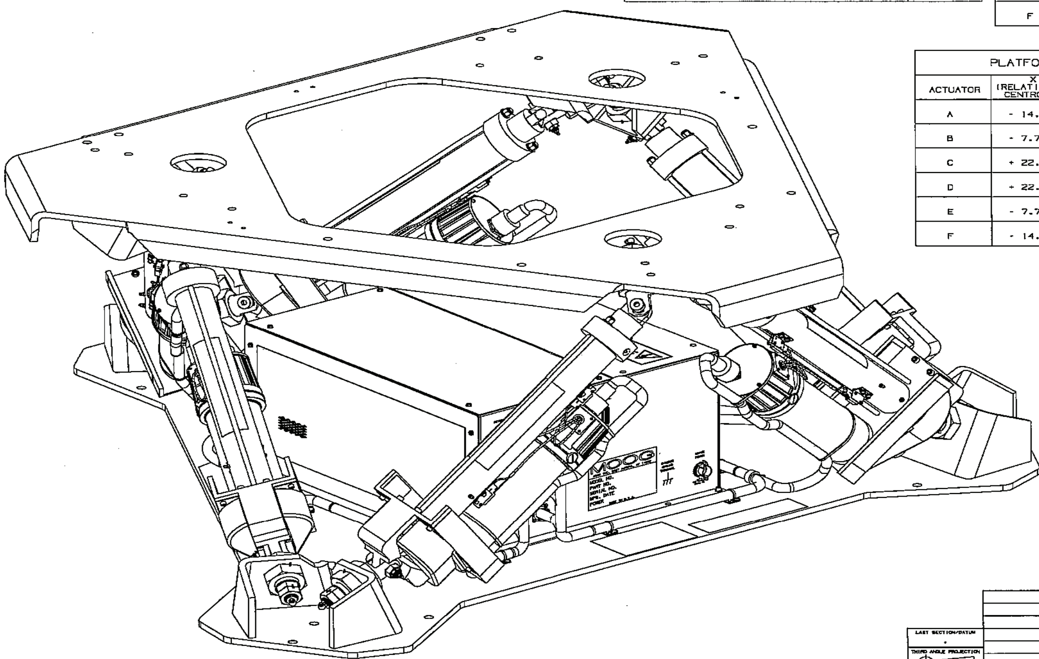
1. DISPLACEMENT CAPABILITIES ARE EXPRESSED AS USEABLE MAXIMUM EXCURSIONS ALLOWING SIMULTANEOUS MOTIONS ACHIEVABLE BY OPERATING ACTUATORS WITHOUT EXCEEDING END OF STROKE SOFTWARE LIMITS.
2. DISPLACEMENT CAPABILITIES ARE EXPRESSED AS USEABLE SINGLE AXIS MOTIONS ABOUT NEUTRAL POSITION. ACHIEVABLE BY OPERATING ACTUATORS WITHOUT EXCEEDING END OF STROKE SOFTWARE LIMITS.
3. DISPLACEMENT CAPABILITIES ARE ABSOLUTE MAXIMUMS AND MAY REQUIRE SIMULTANEOUS MOTIONS AND ACTUATOR TRAVEL THRU CUSHIONS TO MECHANICAL END OF STROKE STOPS.
4. MOTION MECHANICS MUST BE LAGGED TO SUITABLE SURFACE PER USER'S MANUAL INSTRUCTIONS.
5. COORDINATES DEFINED FOR SETTLED (HOME) POSITION AS SHOWN ON SHEET 2.

MOTION CAPABILITIES						
AXIS	DISPLACEMENT 1	DISPLACEMENT 2	DISPLACEMENT 3	VELOCITY	ACCELERATION	POLARITY
ROLL	± 22.4 DEGREES	± 21.0 DEGREES	± 28.6 DEGREES	± 30 DEG/SEC	± 500 DEG/SEC^2	+ = RIGHT EDGE MOVES UP VIEWED FROM FRONT
PITCH	+ 25.4 DEGREES - 23.5 DEGREES	± 22.0 DEGREES	+ 32.2 DEGREES - 29.9 DEGREES	± 30 DEG/SEC	± 500 DEG/SEC^2	+ = FRONT EDGE UP
YAW	± 23.2 DEGREES	± 22.5 DEGREES	± 28.7 DEGREES	± 40 DEG/SEC	± 400 DEG/SEC^2	+ = ROTATES CLOCKWISE VIEWED FROM ABOVE
SURGE	+ 11.1 INCHES - 11.6 INCHES	+ 10.2 INCHES - 9.5 INCHES	+ 13.5 INCHES - 14.3 INCHES	± 20 IN/SEC	± .6 g's	+ = FORWARD
LATERAL	± 11.7 INCHES	± 10.2 INCHES	± 14.3 INCHES	± 20 IN/SEC	± .6 g's	+ = PLATFORM MOVES LEFT VIEWED FROM FRONT
HEAVE	± 7.0 INCHES	± 7.0 INCHES	± 8.6 INCHES	± 12 IN/SEC	- .5/ + .7 g's	+ = DOWN

MOTION CENTROID LOCATION (REF AXIS SHOWN ON PAGE 2)	
AXIS	POSITION
X	39.12
Y	0.0
Z	23.2

PLATFORM WEIGHT	
CUSTOMER PAYLOAD	2200 LB
MOOG FLYING WEIGHT (INCLUDES FLYING FRAME, JOINT HARDWARE AND ACTUATOR COMPONENT WEIGHT)	354 LB
TOTAL LOADED FLYING WEIGHT	2554 LB
TOTAL WEIGHT OF UNLOADED SYSTEM	1400 LB
TOTAL WEIGHT OF LOADED SYSTEM	3600 LB
SHIPPING WEIGHT (SYSTEM ONLY)	1400 LB

BASE JOINT COORDINATES			
ACTUATOR	X (RELATIVE TO CENTROID)	Y (RELATIVE TO CENTROID)	Z (RELATIVE TO GROUND)
A	- 31.00	+ 4.00	- 5.00
B	+ 12.04	+ 28.85	- 5.00
C	+ 18.96	+ 24.85	- 5.00
D	+ 18.96	- 24.85	- 5.00
E	+ 12.04	- 28.85	- 5.00
F	- 31.00	- 4.00	- 5.00



PLATFORM JOINT COORDINATES			
ACTUATOR	X (RELATIVE TO CENTROID)	Y (RELATIVE TO CENTROID)	Z (RELATIVE TO PLATFORM JOINTS)
A	- 14.71	+ 17.49	0.0
B	- 7.79	+ 21.49	0.0
C	+ 22.50	+ 4.00	0.0
D	+ 22.50	- 4.00	0.0
E	- 7.79	- 21.49	0.0
F	- 14.71	- 17.49	0.0

ACTUATOR LENGTHS (INCHES)	
MECH RETRACT STOP	27.9
RETRACT CUSHION	28.6
RETRACT SOFTWARE LIMIT	29.1
EXTEND SOFTWARE LIMIT	40.1
EXTEND CUSHION	40.6
MECH EXTEND STOP	41.3

CUSTOMER ALLOWABLE PAYLOAD MASS PROPERTIES 5	
MAX PAYLOAD (CUSTOMER)	1000 KG (2,200 LB)
CENTER OF GRAVITY LOCATION	
HORIZONTAL	$\leq$0.06 M (2.5 INCHES) FROM CENTROID
VERTICAL	$\leq$0.6 M (24 INCHES) ABOVE FLYING PLATFORM
MASS MOMENT OF INERTIA (RELATIVE TO CENTROID)	5
PITCH AXIS	650 KG - M^2 (5750 in-lb-sec^2)
ROLL AXIS	400 KG - M^2 (3540 in-lb-sec^2)
YAW AXIS	650 KG - M^2 (5750 in-lb-sec^2)

REVISION STATUS OF SHEETS
REVISION STATUS OF ALL SHEETS OF THIS DRAWING IS THE SAME AS SHOWN ON SHEET 1

LAST SECTION/DATUM

THIRD ANGLE PROJECTION

NEXT ASSEMBLY	USED ON
	170E131

ALL DIMENSIONS ARE IN INCHES
PART TO BE FREE OF BURRS

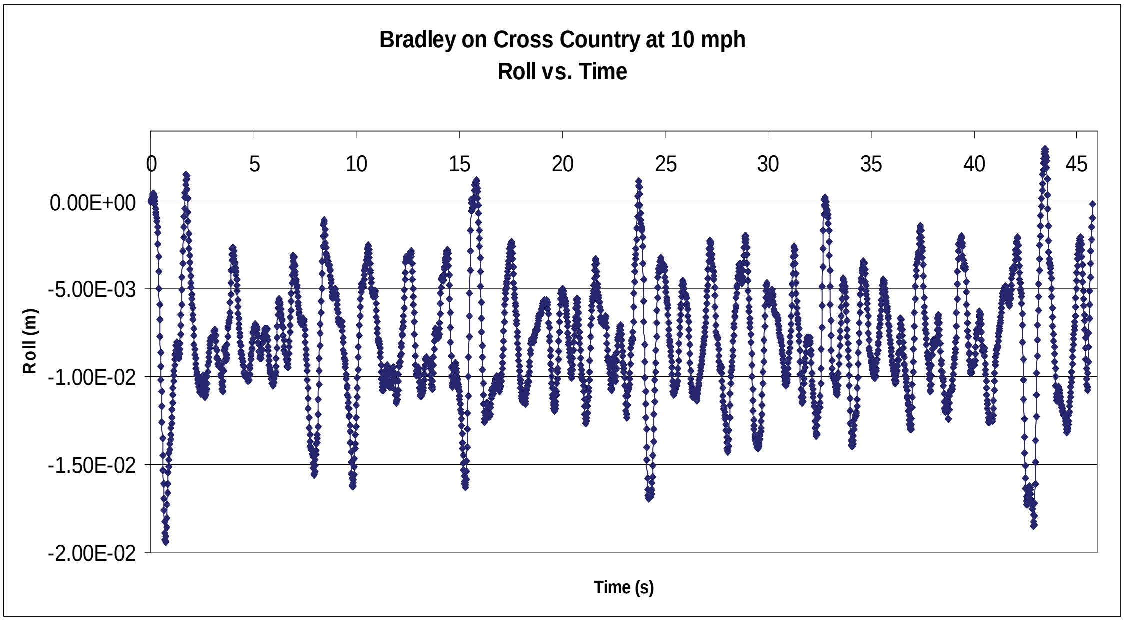
PREPARED	L.R.OVER	19990312
CHECKED	T.PECK	20010201
ENGR	D.FOSTER	19990312

MOOG
MOOG INC., EAST AURORA, NY 14052

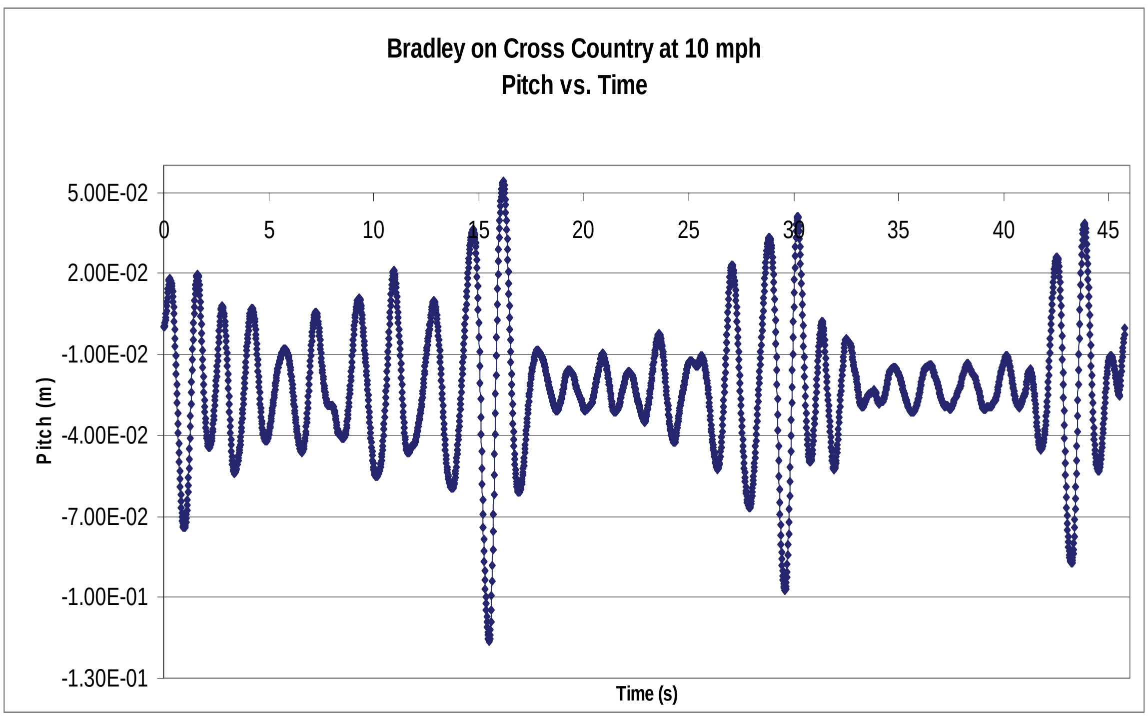
TITLE: 6DOF MOTION MECHANICS INSTALLATION

SIZE: E | CAGE CODE: 94697 | DWG NO. C37963
SCALE 3/8 | SHEET 1 OF 7

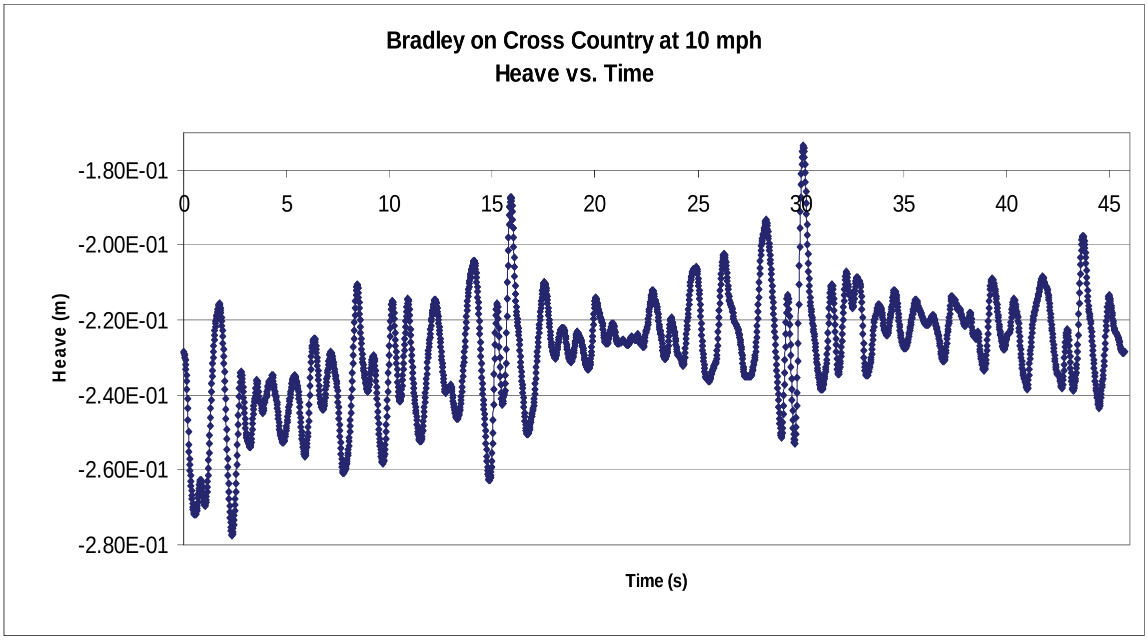
UNIGRAPHICS DATA BASE

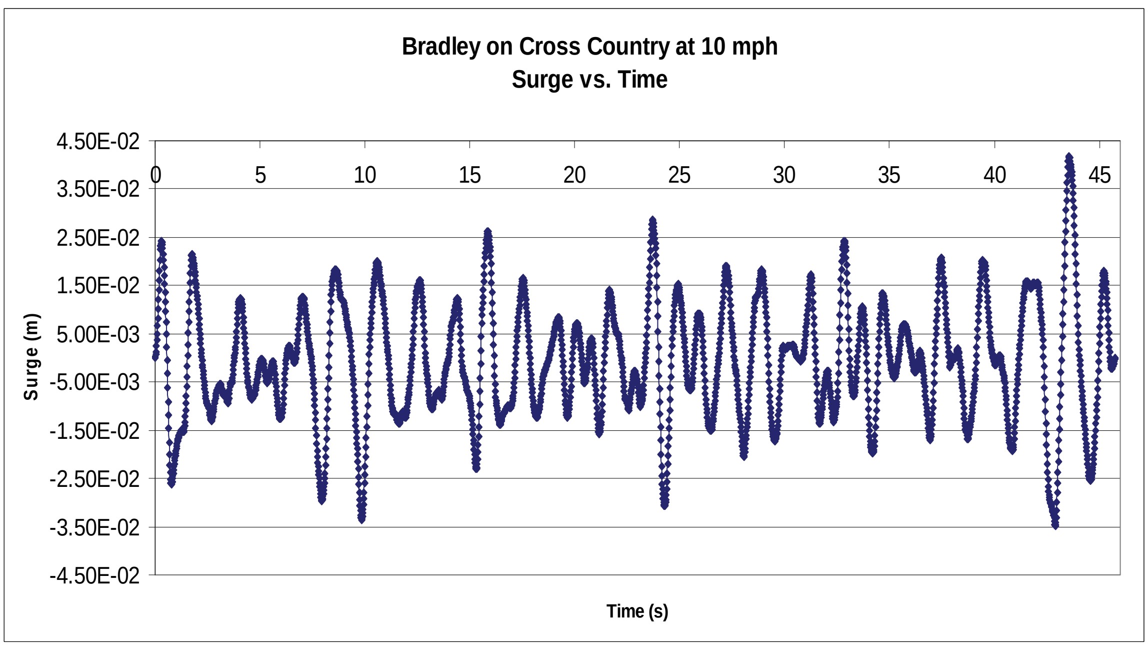


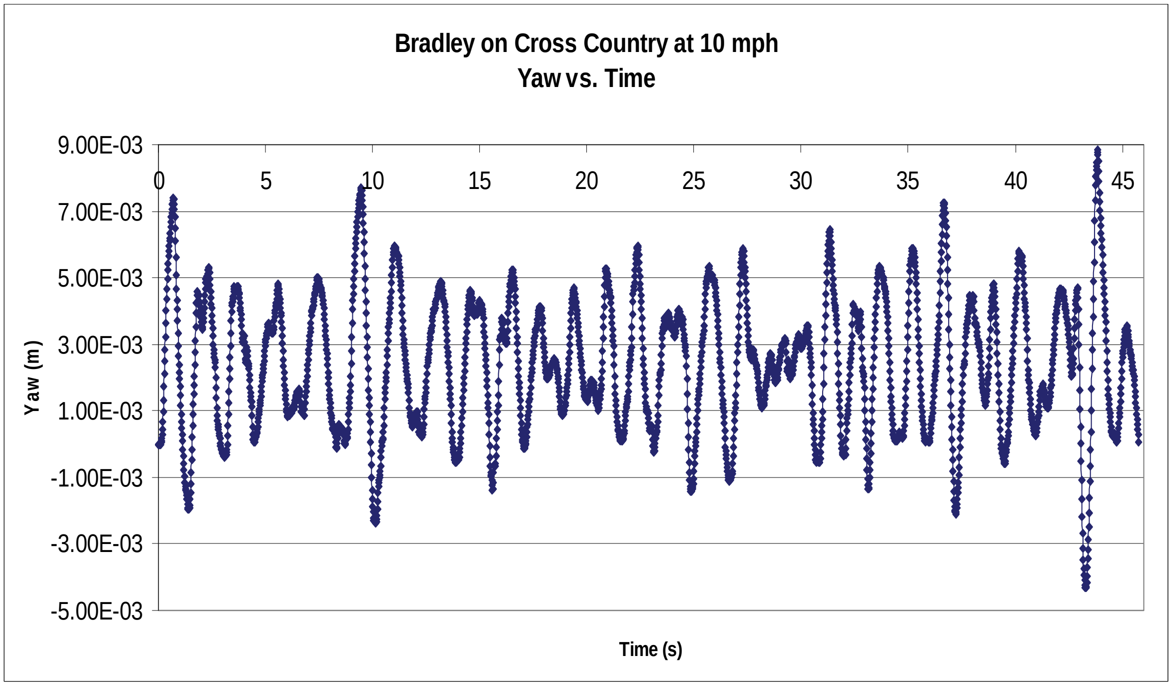
Bradley on Cross Country at 10 mph
Roll vs. Time
0
5
10
15
20
25
30
35
40
45
0.00E+00
-5.00E-03
-1.00E-02
-1.50E-02
-2.00E-02
Roll (m)
Time (s)

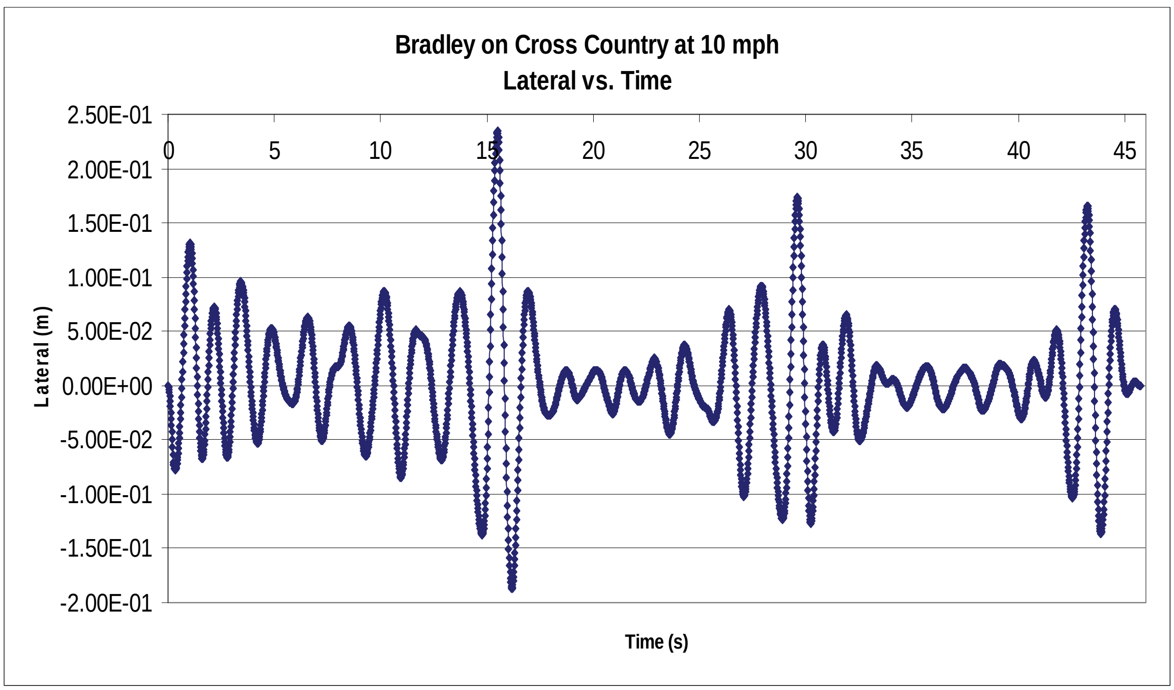


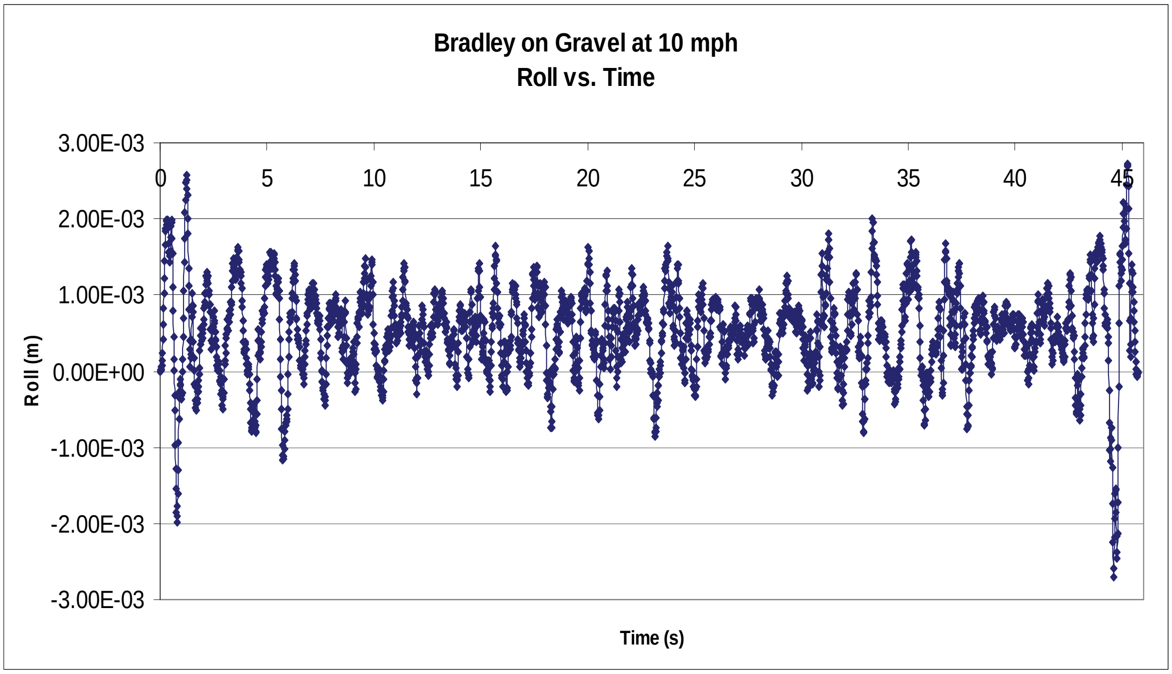
Bradley on Cross Country at 10 mph
Pitch vs. Time
5.00E-02
2.00E-02
-1.00E-02
-4.00E-02
-7.00E-02
-1.00E-01
-1.30E-01
0
5
10
15
20
25
30
35
40
45
Pitch (m)
Time (s)


Bradley on Cross Country at 10 mph
Heave vs. Time
Heave (m)
-1.80E-01
-2.00E-01
-2.20E-01
-2.40E-01
-2.60E-01
-2.80E-01
0
5
10
15
20
25
30
35
40
45
Time (s)

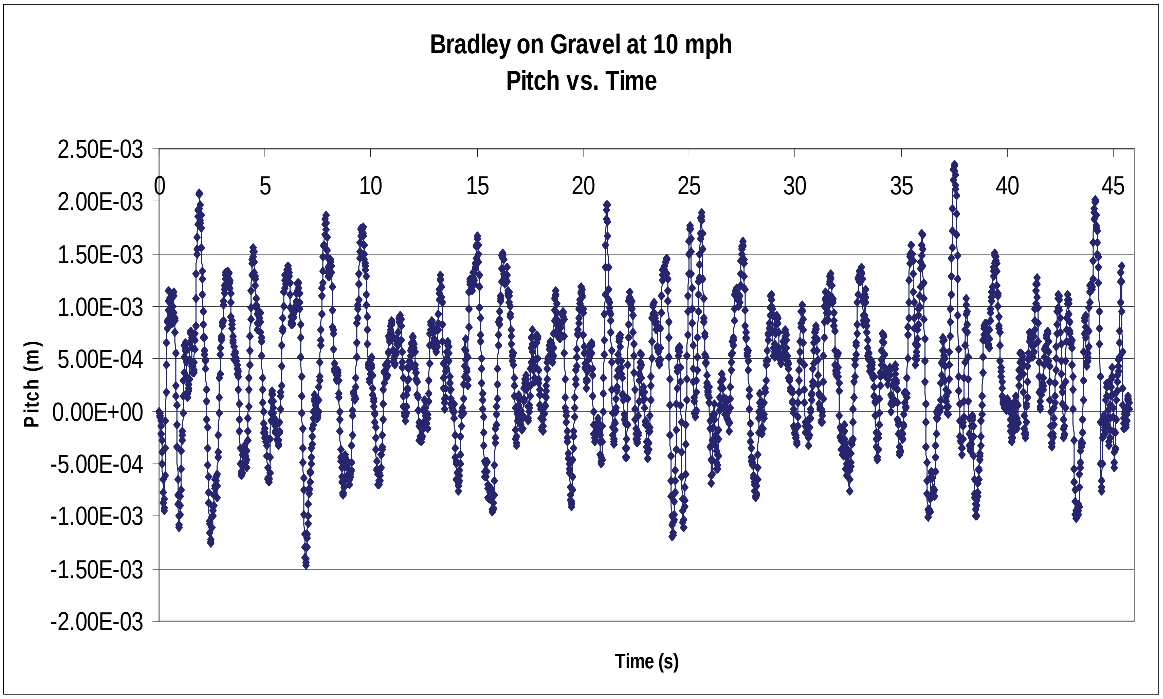

Bradley on Cross Country at 10 mph
Surge vs. Time
Surge (m)
4.50E-02
3.50E-02
2.50E-02
1.50E-02
5.00E-03
-5.00E-03
-1.50E-02
-2.50E-02
-3.50E-02
-4.50E-02
0
5
10
15
20
25
30
35
40
45
Time (s)


Bradley on Cross Country at 10 mph
Yaw vs. Time
9.00E-03
7.00E-03
5.00E-03
3.00E-03
1.00E-03
-1.00E-03
-3.00E-03
-5.00E-03
0
5
10
15
20
25
30
35
40
45
Yaw (m)
Time (s)

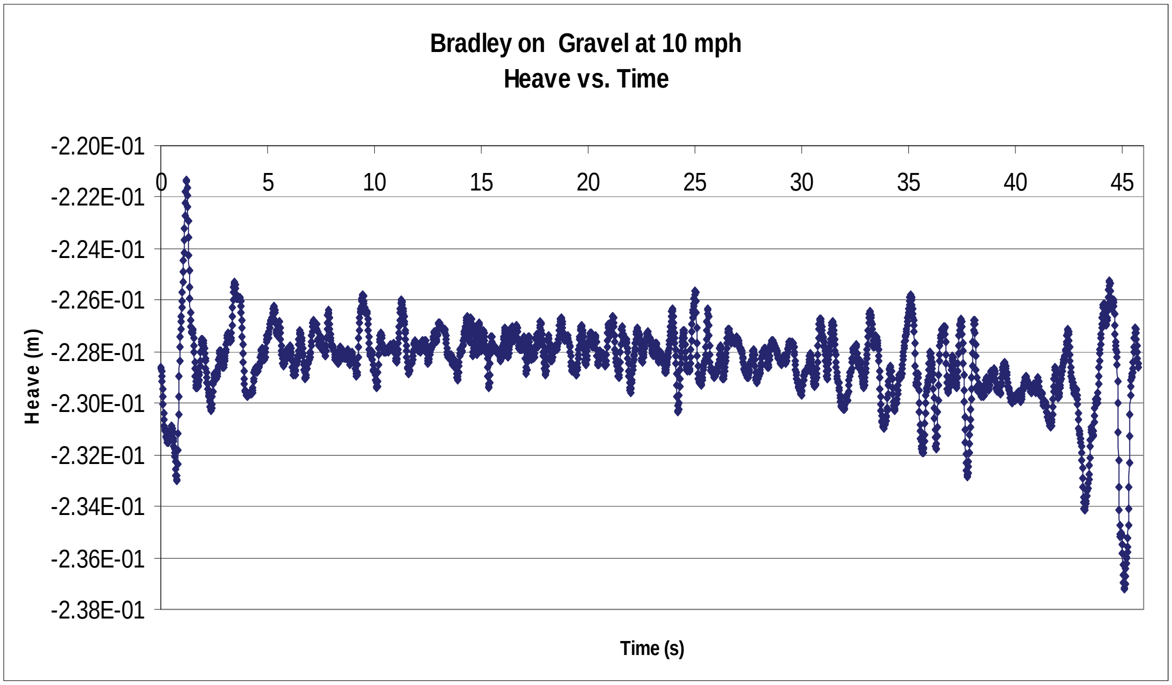

Bradley on Cross Country at 10 mph
Lateral vs. Time
2.50E-01
2.00E-01
1.50E-01
1.00E-01
5.00E-02
0.00E+00
-5.00E-02
-1.00E-01
-1.50E-01
-2.00E-01
0
5
10
15
20
25
30
35
40
45
Lateral (m)
Time (s)

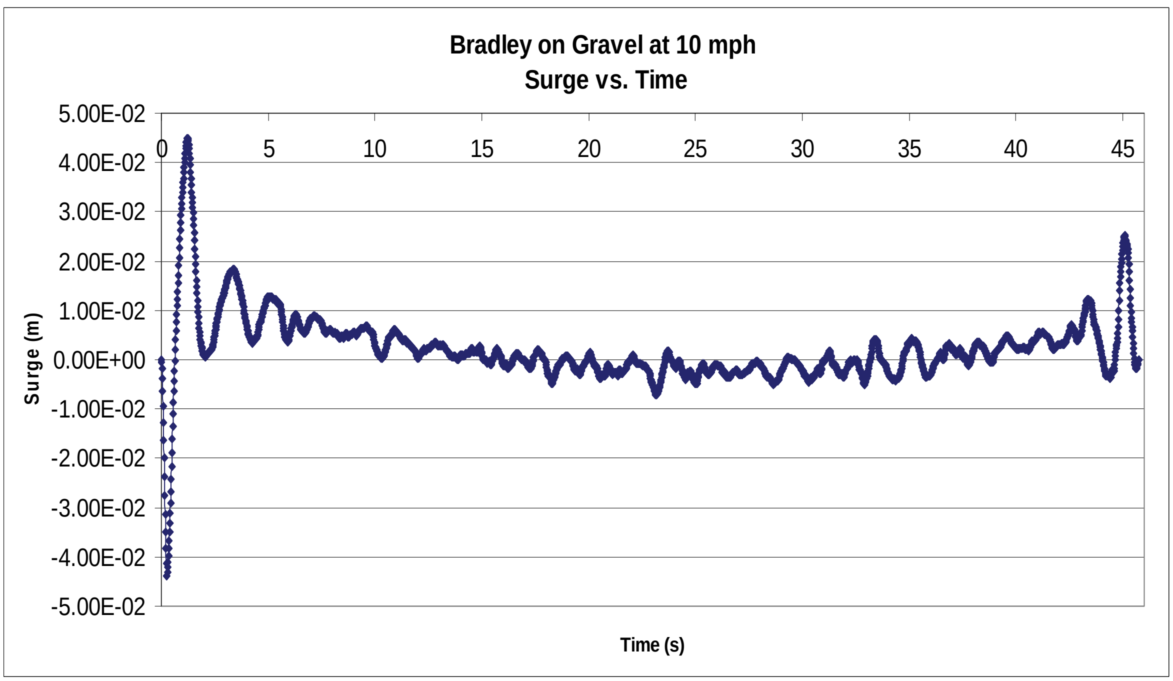


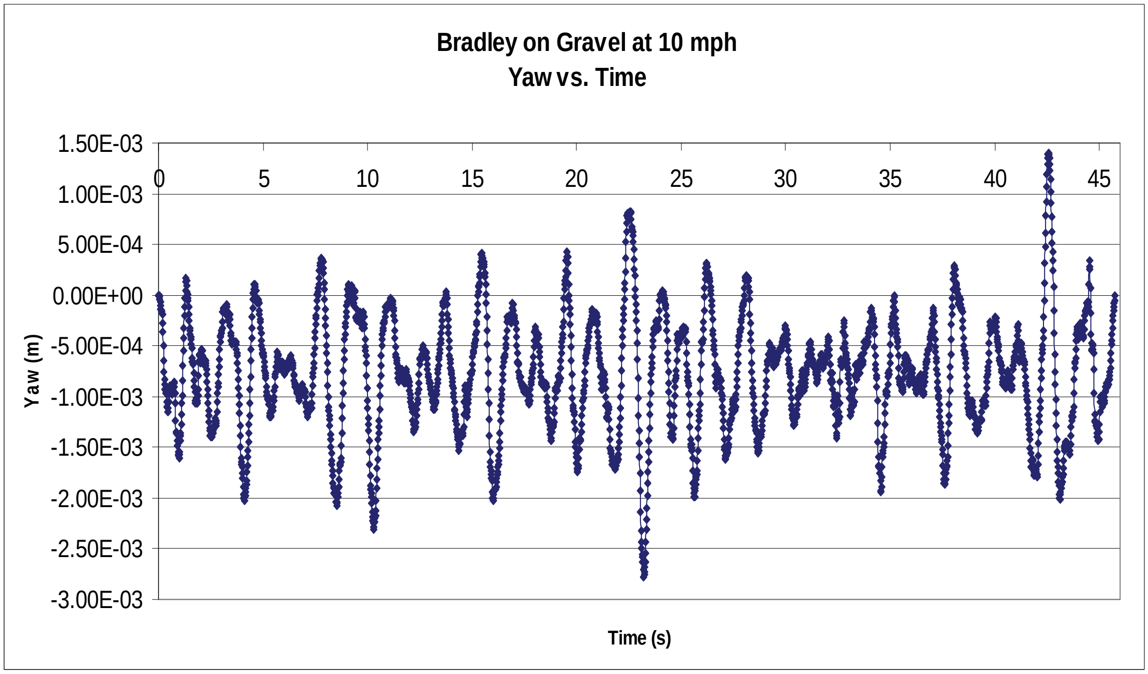
Bradley on Gravel at 10 mph
Roll vs. Time
3.00E-03
2.00E-03
1.00E-03
0.00E+00
-1.00E-03
-2.00E-03
-3.00E-03
0 5 10 15 20 25 30 35 40 45
Roll (m)
Time (s)

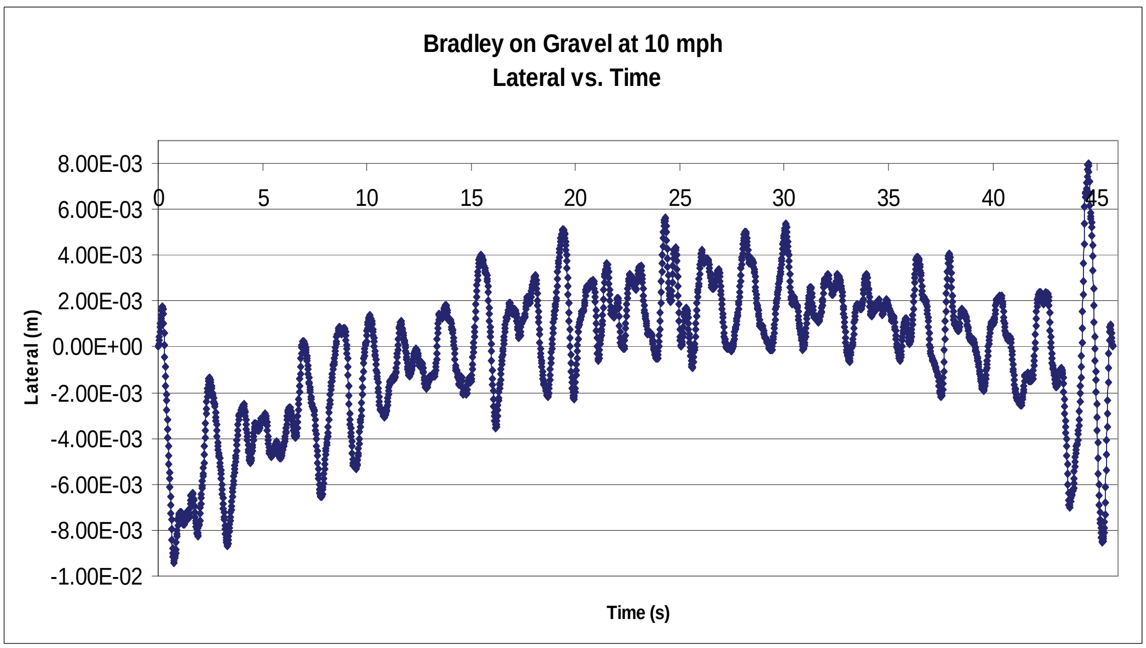


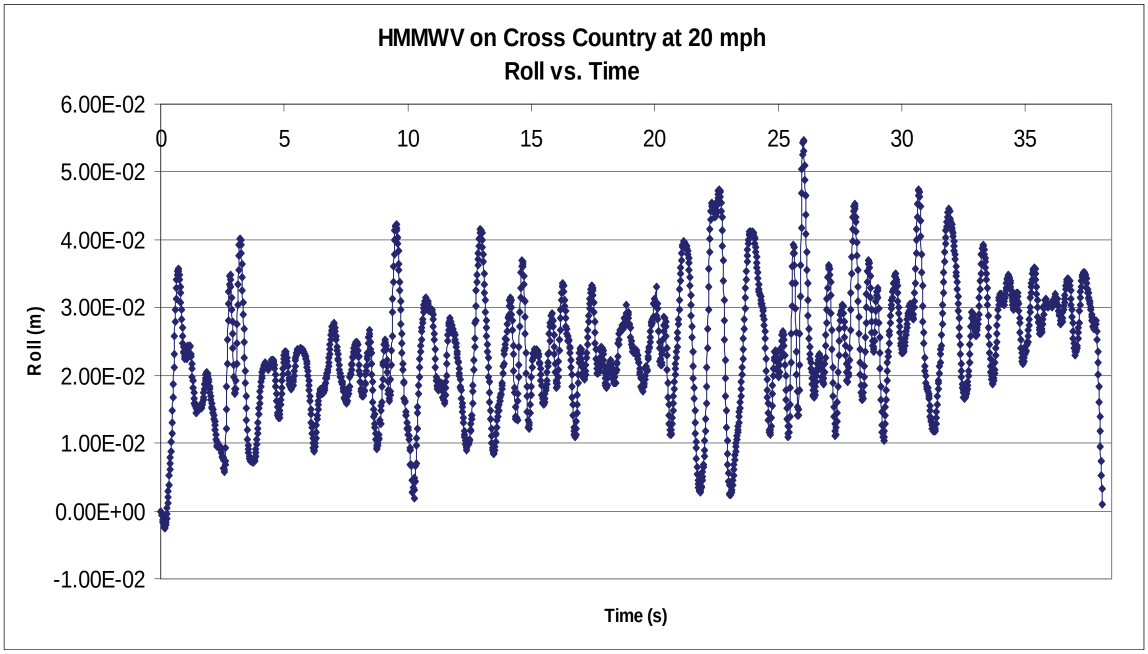
Bradley on Gravel at 10 mph
Pitch vs. Time
2.50E-03
2.00E-03
1.50E-03
1.00E-03
5.00E-04
0.00E+00
-5.00E-04
-1.00E-03
-1.50E-03
-2.00E-03
0 5 10 15 20 25 30 35 40 45
Pitch (m)
Time (s)

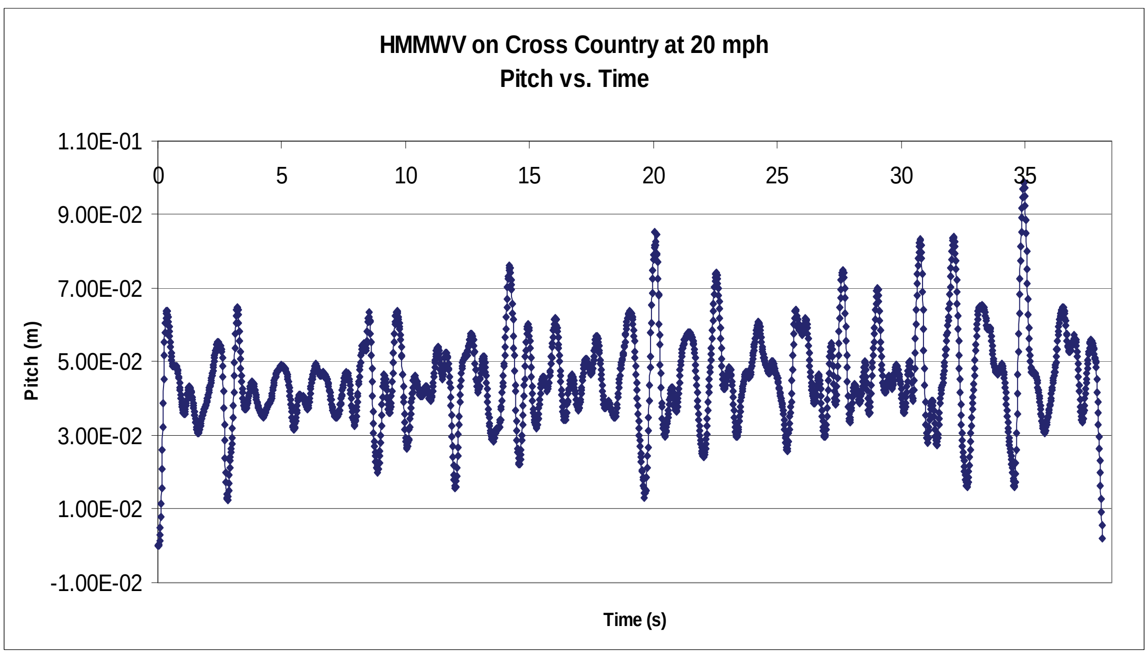

Bradley on Gravel at 10 mph
Heave vs. Time
-2.20E-01
-2.22E-01
-2.24E-01
-2.26E-01
-2.28E-01
-2.30E-01
-2.32E-01
-2.34E-01
-2.36E-01
-2.38E-01
0
5
10
15
20
25
30
35
40
45
Heave (m)
Time (s)

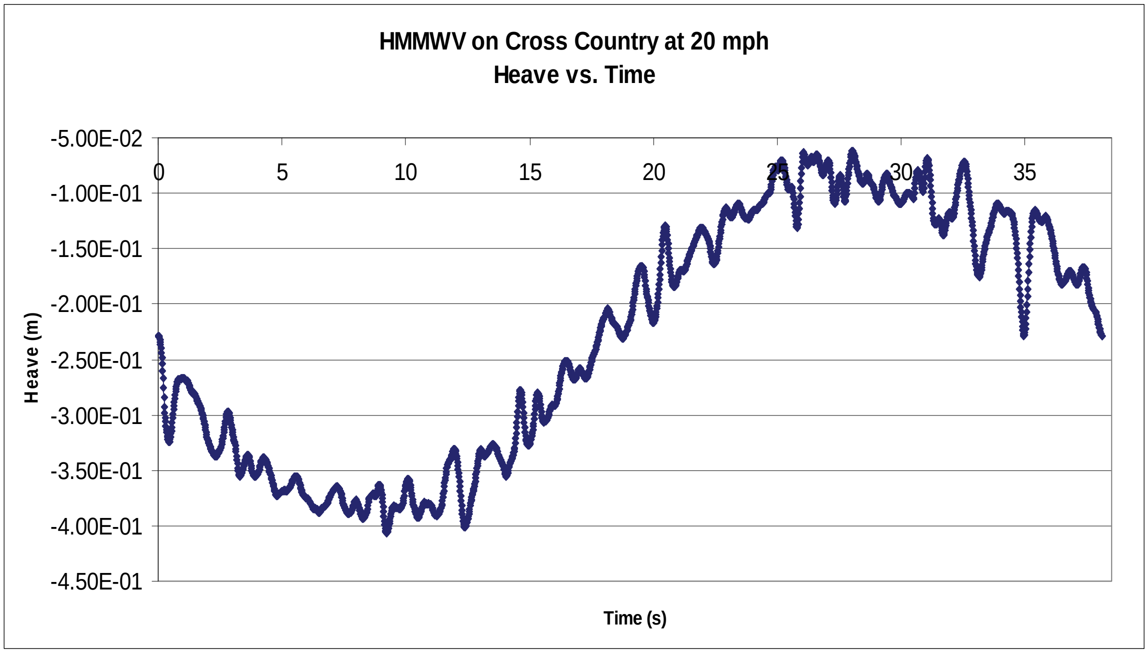

Bradley on Gravel at 10 mph
Surge vs. Time
5.00E-02
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
-1.00E-02
-2.00E-02
-3.00E-02
-4.00E-02
-5.00E-02
0
5
10
15
20
25
30
35
40
45
Surge (m)
Time (s)

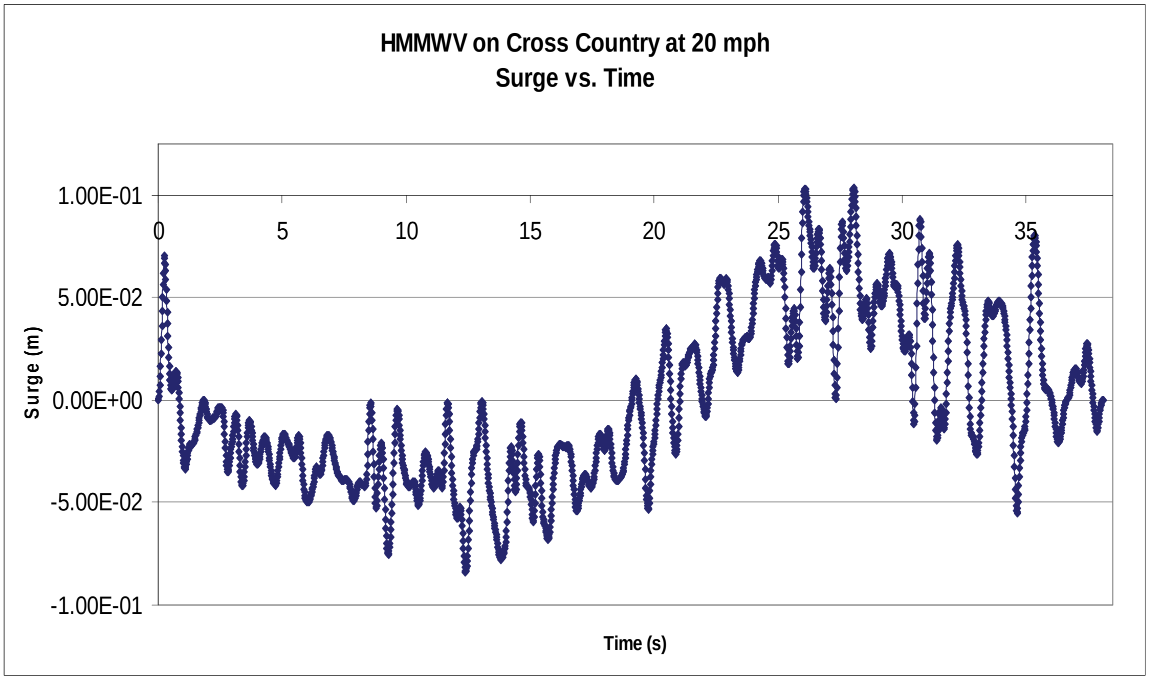

Bradley on Gravel at 10 mph
Yaw vs. Time
Yaw (m)
1.50E-03
1.00E-03
5.00E-04
0.00E+00
-5.00E-04
-1.00E-03
-1.50E-03
-2.00E-03
-2.50E-03
-3.00E-03
0
5
10
15
20
25
30
35
40
45
Time (s)

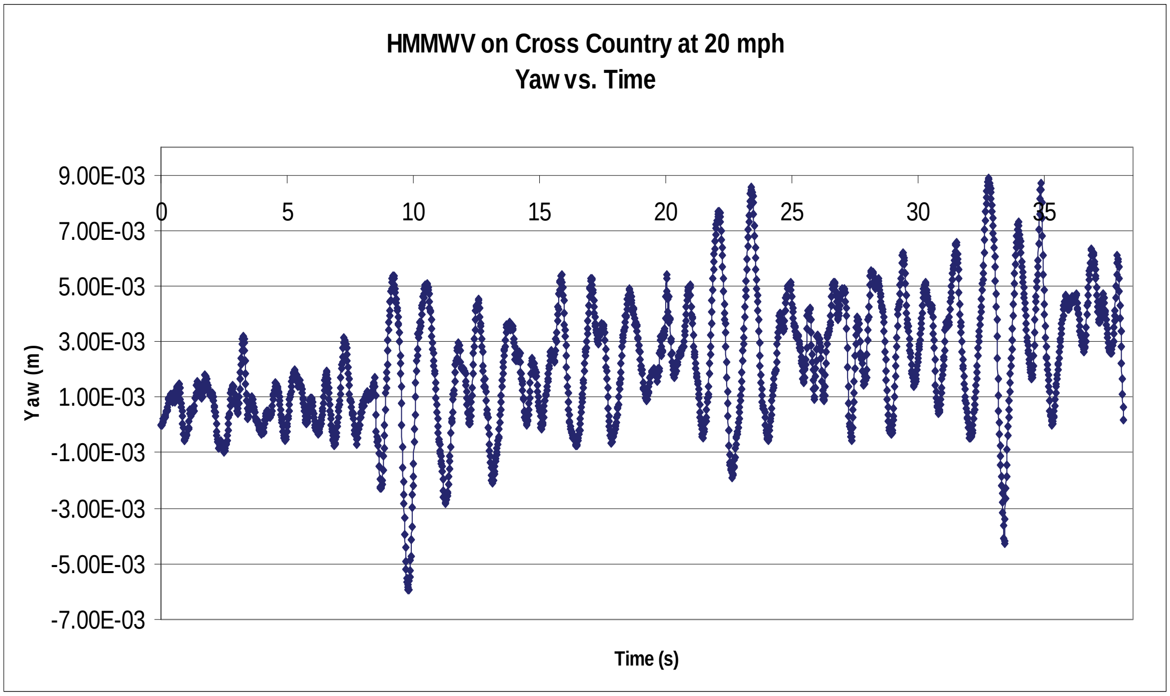

Bradley on Gravel at 10 mph
Lateral vs. Time
Lateral (m)
8.00E-03
6.00E-03
4.00E-03
2.00E-03
0.00E+00
-2.00E-03
-4.00E-03
-6.00E-03
-8.00E-03
-1.00E-02
0
5
10
15
20
25
30
35
40
45
Time (s)

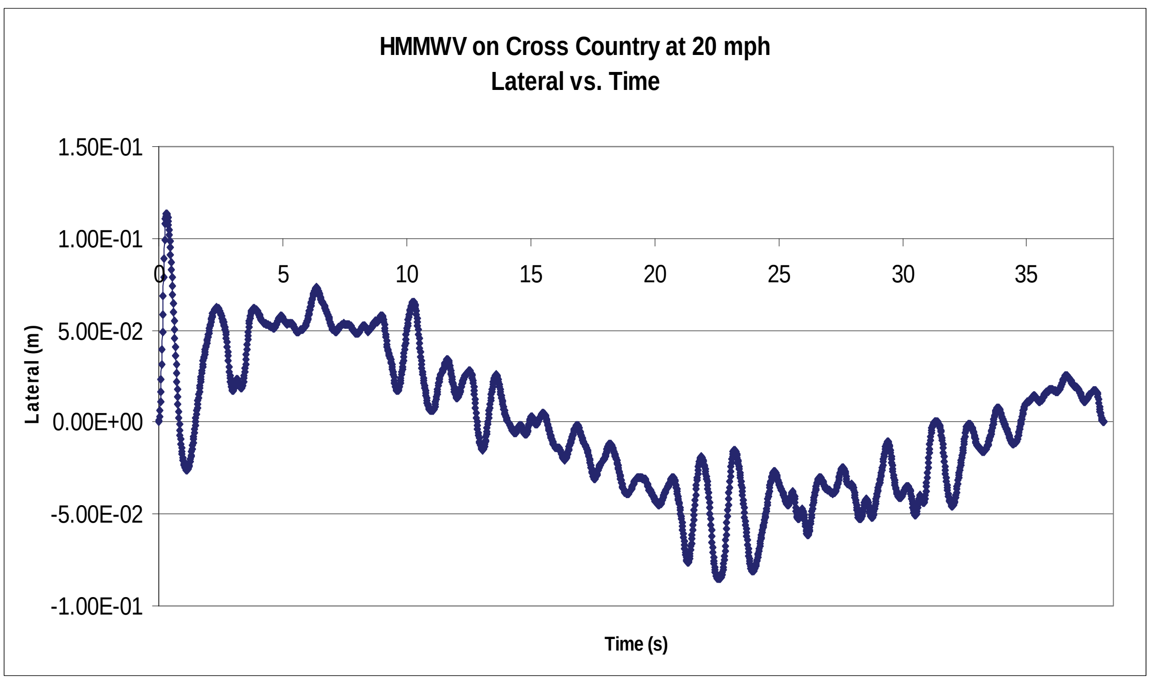

HMMWV on Cross Country at 20 mph
Roll vs. Time
Roll (m)
Time (s)
6.00E-02
5.00E-02
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
-1.00E-02
0
5
10
15
20
25
30
35

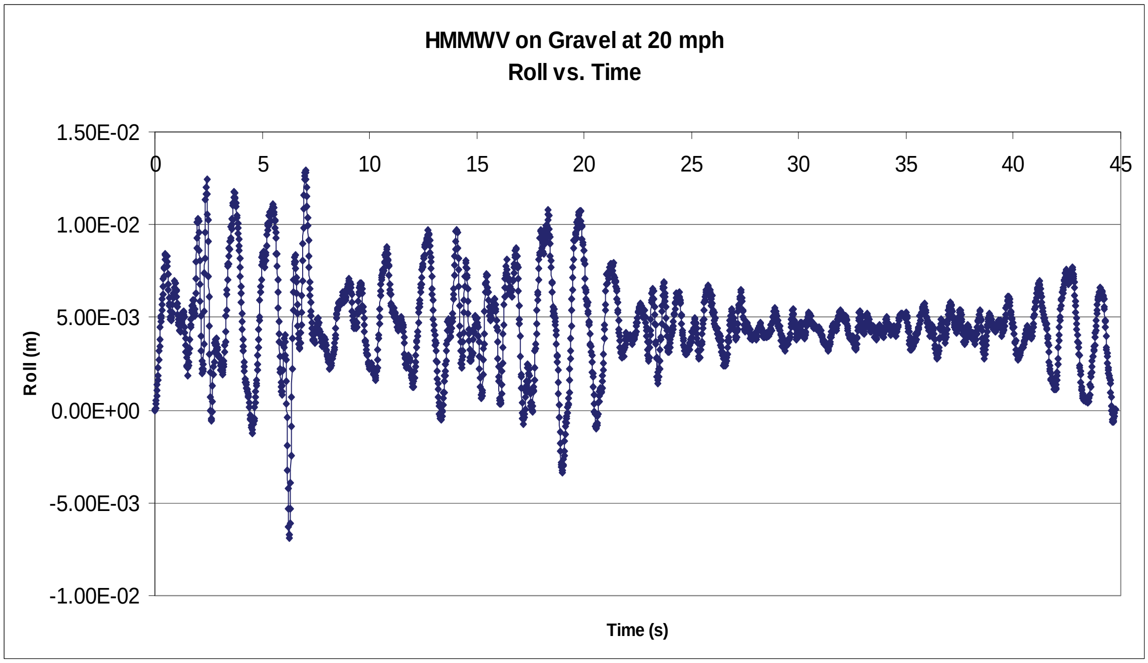

HMMWV on Cross Country at 20 mph
Pitch vs. Time
Pitch (m)
Time (s)
1.10E-01
9.00E-02
7.00E-02
5.00E-02
3.00E-02
1.00E-02
-1.00E-02
0
5
10
15
20
25
30
35

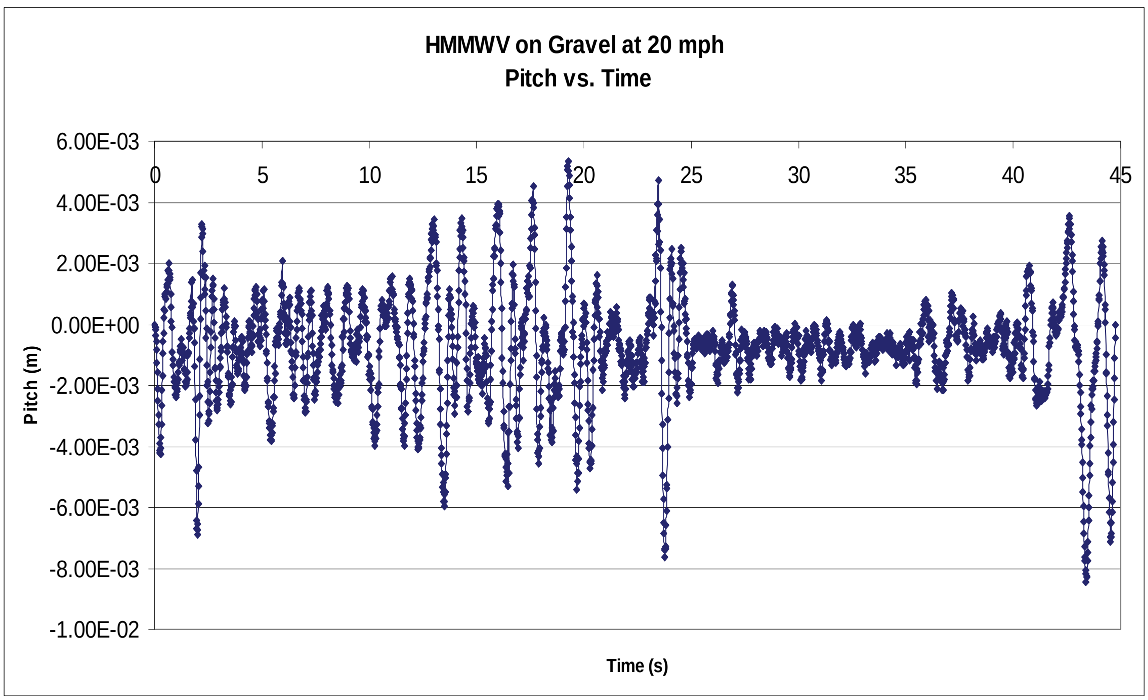

HMMWV on Cross Country at 20 mph
Heave vs. Time
Heave (m)
-5.00E-02
-1.00E-01
-1.50E-01
-2.00E-01
-2.50E-01
-3.00E-01
-3.50E-01
-4.00E-01
-4.50E-01
0
5
10
15
20
25
30
35
Time (s)

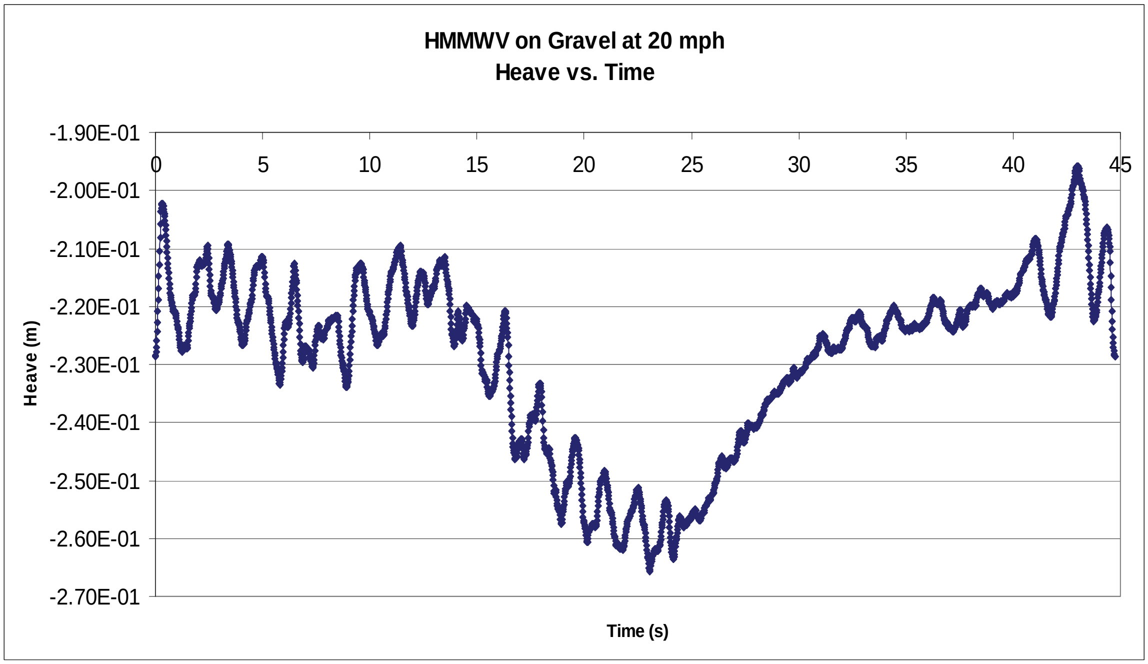

HMMWV on Cross Country at 20 mph
Surge vs. Time
Surge (m)
1.00E-01
5.00E-02
0.00E+00
-5.00E-02
-1.00E-01
0
5
10
15
20
25
30
35
Time (s)

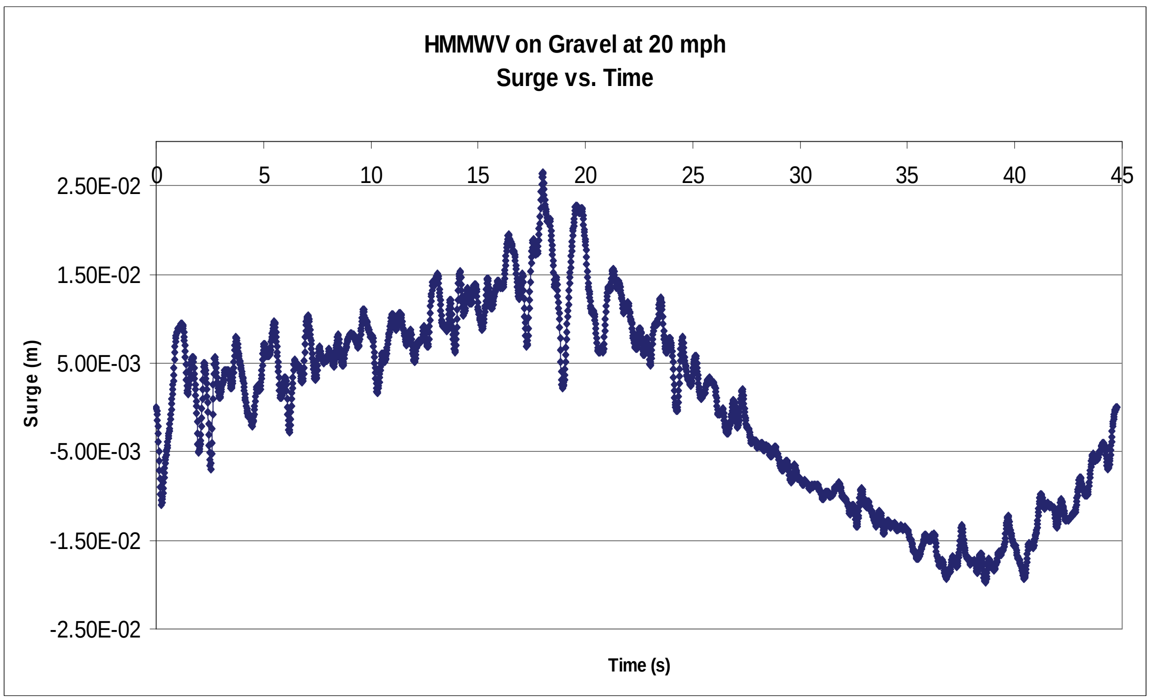

HMMWV on Cross Country at 20 mph
Yaw vs. Time
Yaw (m)
9.00E-03
7.00E-03
5.00E-03
3.00E-03
1.00E-03
-1.00E-03
-3.00E-03
-5.00E-03
-7.00E-03
0
5
10
15
20
25
30
35
Time (s)

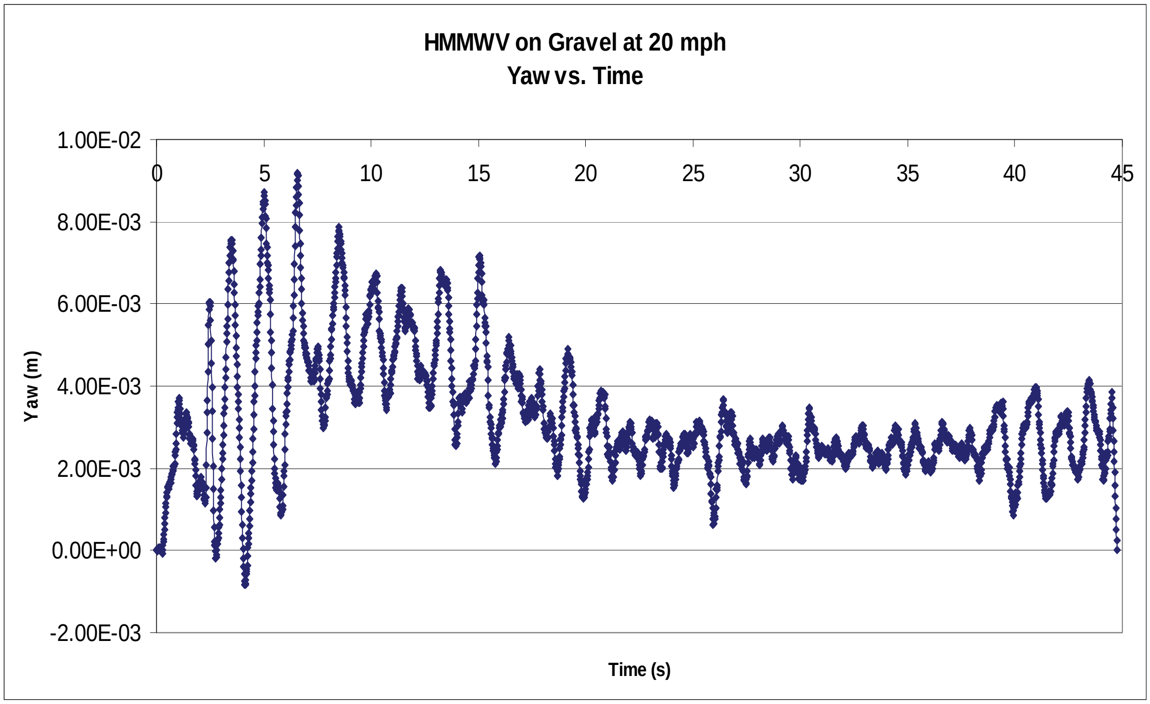

HMMWV on Cross Country at 20 mph
Lateral vs. Time
Lateral (m)
1.50E-01
1.00E-01
5.00E-02
0.00E+00
-5.00E-02
-1.00E-01
0
5
10
15
20
25
30
35
Time (s)

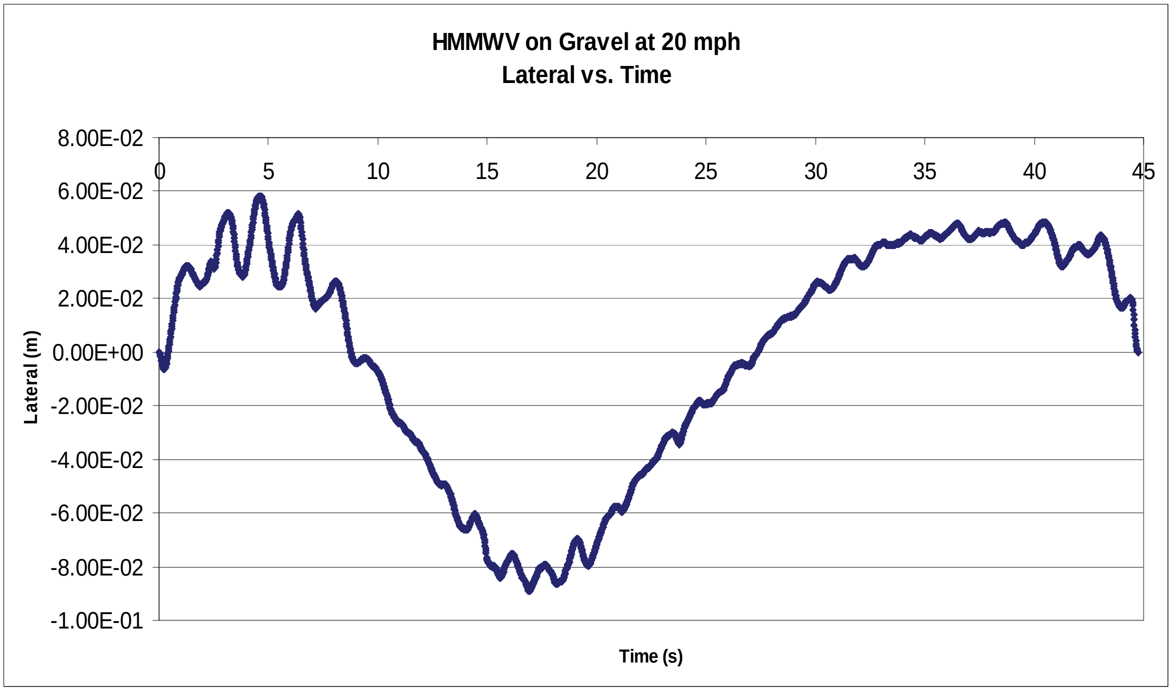

HMMWV on Gravel at 20 mph
Roll vs. Time
1.50E-02
1.00E-02
5.00E-03
0.00E+00
-5.00E-03
-1.00E-02
0
5
10
15
20
25
30
35
40
45
Roll (m)
Time (s)


HMMWV on Gravel at 20 mph
Pitch vs. Time
6.00E-03
4.00E-03
2.00E-03
0.00E+00
-2.00E-03
-4.00E-03
-6.00E-03
-8.00E-03
-1.00E-02
0
5
10
15
20
25
30
35
40
45
Pitch (m)
Time (s)


HMMWV on Gravel at 20 mph
Heave vs. Time
Heave (m)
Time (s)
-1.90E-01
-2.00E-01
-2.10E-01
-2.20E-01
-2.30E-01
-2.40E-01
-2.50E-01
-2.60E-01
-2.70E-01
0
5
10
15
20
25
30
35
40
45


HMMWV on Gravel at 20 mph
Surge vs. Time
Surge (m)
Time (s)
2.50E-02
1.50E-02
5.00E-03
-5.00E-03
-1.50E-02
-2.50E-02
0
5
10
15
20
25
30
35
40
45


HMMWV on Gravel at 20 mph
Yaw vs. Time
Yaw (m)
1.00E-02
8.00E-03
6.00E-03
4.00E-03
2.00E-03
0.00E+00
-2.00E-03
0
5
10
15
20
25
30
35
40
45
Time (s)


HMMWV on Gravel at 20 mph
Lateral vs. Time
Lateral (m)
8.00E-02
6.00E-02
4.00E-02
2.00E-02
0.00E+00
-2.00E-02
-4.00E-02
-6.00E-02
-8.00E-02
-1.00E-01
0
5
10
15
20
25
30
35
40
45
Time (s)

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Appendix B. Health and Demographics Questionnaire

Participant ID ________ Date:________

1. Age:_____ Height:_______ Weight:______ Gender:______

2. Medical Data:

a. Are you currently experiencing the effects of any recent illness (cold, flu, etc.) or injury?

YES NO

b. Are you currently taking any cold or flu medications or any anti-motion sickness medication?

YES NO

c. Have you experienced moderate to severe Simulator Sickness (SS) or motion sickness (MS)?

SS: Mild/None Moderate Severe MS: Mild/None Moderate Severe

d. Do you have any medical concerns that would possibly be aggravated by participating in this study (i.e. back or neck problems)?

YES NO

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Appendix C. Volunteer Agreement Affidavit

VOLUNTEER AGREEMENT AFFIDAVIT:

ARL-HRED Local Adaptation of DA Form 5303-R. For use of this form, see AR 70-25 or AR 40-38

The proponent for this research is:	**U.S. Army Research Laboratory Human Research and Engineering Directorate Aberdeen Proving Ground, MD 21005**

Authority:	Privacy Act of 1974, 10 U.S.C. 3013, [Subject to the authority, direction, and control of the Secretary of Defense and subject to the provisions of chapter 6 of this title, the Secretary of the Army is responsible for, and has the authority necessary to conduct, all affairs of the Department of the Army, including the following functions: (4) Equipping (including research and development), 44 USC 3101 [The head of each Federal agency shall make and preserve records containing adequate and proper documentation of the organization, functions, policies, decisions, procedures, and essential transactions of the agency and designed to furnish the information necessary to protect the legal and financial rights of the Government and of persons directly affected by the agency's activities]
Principal purpose:	To document voluntary participation in the Research program.
Routine Uses:	The SSN and home address will be used for identification and locating purposes. Information derived from the project will be used for documentation, adjudication of claims, and mandatory reporting of medical conditions as required by law. Information may be furnished to Federal, State, and local agencies.
Disclosure:	The furnishing of your SSN and home address is mandatory and necessary to provide identification and to contact you if future information indicates that your health may be adversely affected. Failure to provide the information may preclude your voluntary participation in this data collection.

Part A • Volunteer agreement affidavit for subjects in approved Department of Army research projects

Note: Volunteers are authorized medical care for any injury or disease that is the direct result of participating in this project (under the provisions of AR 40-38 and AR 70-25).

Title of Research Project:	**Detection and localization of tactile signals in moving vehicles**	
Human Use Protocol Log #	**ARL-20098-**	
Principal Investigators:	Andrea Krausman	Phone: 410-278-5933 E-Mail: ahynes@arl.army.mil
	Timothy White	Phone: 410-278-5884 E-Mail: twhite@arl.army.mil
Associate Investigator(s)		
Location of Research:	Aberdeen Test Center, Building 860	
Dates of Participation:	May 22-26	

Part B • To be completed by the Principal Investigator

Note: Instruction for elements of the informed consent provided as detailed explanation in accordance with
Appendix C, AR 40-38 or AR 70-25.

Purpose of the Research

You are invited to participate in a study designed to evaluate the detectability of tactile signals in moving vehicles. This study is being conducted by the Army Research Laboratory (ARL) – Human Research Engineering Directorate (HRED).

Procedures

Before beginning the experiment, you will complete a health and demographics questionnaire to assess your eligibility to participate in this experiment. You may not be eligible to participate in this study if: (1) your physician has recommended that you avoid high vibration or impact environments, or (2) you have neck or back problems that may be worsened by participating.

After completing the health and demographics questionnaire, you will receive a brief orientation to the two types of tactile equipment, tactile belts, and the ride motion simulator (RMS) that will be used. During this time, you are free to ask questions. Then, you will don a t-shirt and a tactile belt, and complete a brief training session so that you can become familiar with the vibrations and how to respond when you receive them.

Next, you will be seated on the RMS and will complete a practice session. During the practice session, the simulator will be moving and you will receive several tactile signals. When you receive the signals you will verbally indicate the location where you felt the signal.

A baseline will be taken prior to the actual experiment. You will sit on the RMS while it is stationary and receive several tactile signals. Again, you will verbally indicate the location where you felt the signal. Two sessions will be completed; one with each tactile system.

For the actual experiment, you will don one of the tactile systems and will sit on the RMS and experience the simulated ride of a HMMWV and Bradley over a gravel road and a cross country course. As you ride, you will receive tactile signals and will verbally indicate the location where you felt the signal. After you complete the trials with one tactile system, you will don the other tactile system and follow the same procedures. The total time to complete the experiment is approximately 1.5 hours.

Benefits

You will receive no benefits from participating in the project, other than the personal satisfaction of supporting the development of tactile displays.

Risks

Risks associated with this evaluation are minimal and are less than those encountered by soldiers or marines during their normal field training exercises. Standard safety procedures will be followed for the RMS. Members of the test administration staff will be close to you throughout all evaluation trials to assist you should a problem arise. Care will be taken to minimize risks. However, some risks are associated with use of the RMS including fatigue from sitting or from motion sickness, and minimal risks of blunt trauma from physical motion. To minimize risks, you will be required to remain seated with your safety belt fastened when the RMS is in motion, and an emergency 'Stop' button will be provided for your use to stop RMS motion at any time. Ingress and egress from the RMS will be accomplished with moveable stairs with handrails that will be placed at the RMS. At all times, you will be within visual sight and voice communication range with an experimenter.

Confidentiality

All data and information obtained about you will be considered privileged and held in confidence. Photographic or video images of you taken during this data collection will not be identified with any of your personal information (name, rank, or status). Complete confidentiality cannot be promised, particularly if you are a military service member, because information bearing on your health may be required to be reported to appropriate medical or command authorities. In addition, applicable regulations note the possibility that the U.S. Army Medical Research and Materiel Command (MRMC-RCQ) officials may inspect the records.

Disposition of Volunteer Agreement Affidavit

The Principal Investigator will retain the original signed Volunteer Agreement Affidavit and forward a photocopy of it to the Chair of the Human Use Committee after the data collection. The Principal Investigator will provide a copy of the signed and initialed Affidavit to you.

Obtaining ASVAB Scores

IF YOU ARE AN ACTIVE DUTY ENLISTED MILITARY VOLUNTEER, we would like to obtain your Armed Services Vocational Aptitude Battery (ASVAB) scores for potential data analysis. The ASVAB scores would be used strictly for research purposes. The results of any such analyses would be presented for the group of participants as a whole; and no names will be used. With your permission, we will obtain these scores by sending a copy of this signed consent form along with your Social Security Number to the Defense Manpower Data Center (DMDC) in Seaside, CA where ASVAB scores may be obtained from their databases in Arlington, VA or Seaside, CA. If you do not wish your ASVAB scores to be released to the principal investigator, you will still be allowed to participate in the research.

If you would like to participate in this research, please sign one of the following statements, and then complete the information requested at the end of this form:

I **DO AUTHORIZE** you to obtain my ASVAB scores. ______________________________
(Your Signature)

I **DO NOT AUTHORIZE** you to obtain my ASVAB scores. ______________________________
(Your Signature)

Contacts for Additional Assistance

If you have questions concerning your rights on research-related injury, or if you have any complaints about your treatment while participating in this research, you can contact:

Chair, Human Use Committee
U.S. Army Research Laboratory
Human Research and Engineering Directorate
Aberdeen Proving Ground, MD 21005
(520) 538-4705 or (DSN) 879-4705

Office of the Chief Counsel
U.S. Army Research Laboratory
2800 Powder Mill Road
Adelphi, MD 20783-1197
(301) 394-1070 or (DSN) 290-1070

I do hereby volunteer to participate in the research project described in this document. I have full capacity to consent and have attained my 18th birthday. The implications of my voluntary participation, duration, and purpose of the research project, the methods and means by which it is to be conducted, and the inconveniences and hazards that may reasonably be expected have been explained to me. I have been given an opportunity to ask questions concerning this research project. Any such questions were answered to my full and complete satisfaction. Should any further questions arise concerning my rights or project related injury, I may contact the **ARL-HRED Human Use Committee Chairperson at Aberdeen Proving Ground, Maryland, USA by telephone at (520) 538-4705 or DSN 879-4705** I understand that any published data will not reveal my identity. If I choose not to participate, or later wish to withdraw from any portion of it, I may do so without penalty. I understand that military personnel are not subject to punishment under the Uniform Code of Military Justice for choosing not to take part as human volunteers and that no administrative sanctions can be given me for choosing not to participate. I may at any time during the course of the project revoke my consent and withdraw without penalty or loss of benefits. However, I may be required (military volunteer) or requested (civilian volunteer) to undergo certain examinations if, in the opinion of an attending physician, such examinations are necessary for my health and well being.

Printed Name Of Volunteer (First, MI., Last)	
Social Security Number (SSN)	***Permanent Address Of Volunteer***
Date Of Birth (Month, Day, Year)	
Today's Date (Month, Day, Year)	***Signature Of Volunteer***
Signature Of Administrator	

Appendix D. Descriptive Statistics (means and standard deviations)

Baseline (Overall percent correct)

System	Mean	SD
MIT	90.6	22.1
TACTICS 1	98.4	8.8
TACTICS 2	96.9	12.2

Bradley (Percent detected)

System x Terrain

System	Terrain	Mean	SD
MIT	Cross country	82.8	31.5
	Gravel	98.9	7.2
TACTICS 1	Cross country	97.4	11.2
	Gravel	99.5	5.1
TACTICS 2	Cross country	93.8	20.8
	Gravel	96.9	12.2

Terrain x Position

Terrain	Position	Mean	SD
Cross country	N	95.8	14.0
	NE	97.2	11.6
	E	93.1	17.5
	SE	94.4	15.9
	S	75.0	38.7
	SW	87.5	30.2
	W	91.7	25.4
	NW	95.8	14.0
Gravel	N	100	0
	NE	98.6	8.3
	E	95.8	14.0
	SE	97.2	11.6
	S	97.2	11.6
	SW	98.6	8.3
	W	100	0
	NW	100	0

Terrain

Terrain	Mean	SD
Cross country	91.3	23.5
Gravel	98.4	8.7

System

System	Mean	SD
MIT	90.9	24.2
TACTICS 1	98.4	8.7
TACTICS 2	95.3	17.1

Location

Location	Mean	SD
N	97.9	10.1
NE	97.9	10.1
E	94.4	15.8
SE	95.8	13.9
S	86.1	30.5
SW	93.1	22.7
W	95.8	18.3
NW	97.9	10.1

Bradley (Overall percent correct)

System x Terrain

System	Terrain	Mean	SD
MIT	Cross country	76.6	33.9
	Gravel	94.3	17.6
TACTICS 1	Cross country	93.2	20.0
	Gravel	97.4	11.2
TACTICS 2	Cross country	91.2	22.9
	Gravel	95.3	16.3

System x Position

System	Position	Mean	SD
	N	91.7	19.0
	NE	97.9	10.2
	E	91.7	19.0
MIT	SE	85.4	23.2
	S	70.8	38.8
	SW	83.3	31.9
	W	81.3	35.5
	NW	81.3	32.3
	N	100	0
	NE	95.8	14.1
	E	89.6	25.4
TACTICS 1	SE	100	0
	S	95.8	14.1
	SW	95.8	14.1
	W	87.5	26.6
	NW	97.9	10.2
	N	96.5	10.2
	NE	95.8	16.9
	E	88.2	28.2
TACTICS 2	SE	94.4	10.2
	S	84.7	30.4
	SW	90.9	22.4
	W	87.5	16.9
	NW	92.4	10.2

Terrain

Terrain	Mean	SD
Cross country	86.9	27.3
Gravel	95.7	15.3

System

System	Mean	SD
MIT	85.4	28.4
TACTICS 1	95.3	16.3
TACTICS 2	93.2	19.9

HMMWV (Percent detected)

System x Terrain

System	Terrain	Mean	SD
MIT	Cross country	81.3	30.9
	Gravel	97.9	10.0
TACTICS 1	Cross country	97.9	10.0
	Gravel	98.4	8.7
TACTICS 2	Cross country	88.0	26.9
	Gravel	95.8	17.3

Terrain x Position

Terrain	Position	Mean	SD
Cross country	N	91.7	18.9
	NE	98.6	8.3
	E	97.2	11.6
	SE	83.3	31.6
	S	72.2	36.7
	SW	84.7	31.2
	W	88.9	24.2
	NW	95.8	14.0
Gravel	N	97.2	11.6
	NE	100	0
	E	98.6	8.3
	SE	98.6	8.3
	S	88.9	24.2
	SW	95.8	18.4
	W	100	0
	NW	100	0

System x Position

System	Position	Mean	SD
	N	95.8	14.1
	NE	97.9	10.2
	E	97.9	10.2
MIT	SE	81.3	32.3
	S	72.9	36.1
	SW	83.3	31.9
	W	91.7	19.0
	NW	95.8	14.1
	N	95.8	14.1
	NE	100	0
	E	97.9	10.2
TACTICS 1	SE	97.9	10.2
	S	95.8	14.1
	SW	97.9	10.2
	W	100	0
	NW	100	0
	N	91.7	19.0
	NE	100	0
	E	97.9	10.2
TACTICS 2	SE	93.8	22.4
	S	72.9	36.1
	SW	89.6	29.4
	W	91.7	24.1
	NW	97.9	10.2

Terrain

Terrain	Mean	SD
Cross country	89.1	25.3
Gravel	97.4	12.6

System

System	Mean	SD
MIT	89.6	24.4
TACTICS 1	98.2	9.4
TACTICS 2	91.93	22.8

Location

Location	Mean	SD
N	94.4	15.8
NE	99.3	5.9
E	97.9	10.0
SE	90.9	24.2
S	80.6	32.0
SW	90.3	26.1
W	94.4	17.9
NW	97.9	10.0

HMMWV (Overall percent correct)

System x Terrain

System	Terrain	Mean	SD
MIT	Cross country	75.5	32.4
	Gravel	94.27	16.0
TACTICS 1	Cross country	97.4	11.2
	Gravel	95.3	16.3
TACTICS 2	Cross country	85.42	28.9
	Gravel	92.71	20.5

Terrain

Terrain	Mean	SD
Cross country	86.1	27.3
Gravel	94.1	17.8

System

System	Mean	SD
MIT	84.9	27.2
TACTICS 1	96.4	14.0
TACTICS 2	89.1	25.3

Location

Location	Mean	SD
N	93.8	16.6
NE	98.6	8.3
E	90.3	21.6
SE	90.9	24.2
S	79.9	32.1
SW	88.2	27.2
W	84.7	27.4
NW	94.4	15.8

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